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ABSTRACT

This teacher's guide is designed to provide science teachers with the necessary guidance and suggestions for teaching about energy and the environment. In this book, energy is discussed as one aspect of a general problem in environmental chemistry. The material in this book can be integrated with the other modules in a sequence that helps students see that chemistry is a unified science. Contents include: (1) "The Balance in Environment"; (2) "Water Environment"; (3) "Toxic Substances in the Environment"; (4) "The Air Environment"; (5) "Energy Sources and Uses"; and (6) "Future Sources of Energy". (KHR)

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TEACHER'S GUIDE

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THE DELICATE BALANCE

AN ENERGY AND THE ENVIRONMENT CHEMISTRY MODULE

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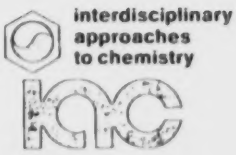

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interdisciplinary approaches to chemistry

IAC

TEACHER'S GUIDE

THE DELICATE BALANCE

AN ENERGY AND THE ENVIRONMENT CHEMISTRY MODULE

Glen Gordon
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Amado Sandoval

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TEACHER'S GUIDE

THE DELICATE BALANCE:
AN ENERGY AND THE ENVIRONMENT CHEMISTRY MODULE

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Introducing The Delicate Balance

The first edition of *The Delicate Balance* was published during the early 1970s, when national awareness of environmental problems was at its height. At that time, a growing concern existed over the conflict between the need for energy and the desire for improved environmental quality. This anxiety arose because many of our major environmental problems were aggravated by the production and use of energy. During the past several years, these problems have intensified to a crisis stage. As a result the "energy crisis" and the search for solutions to energy problems have now become a dominant national issue. Because of its importance, the coverage of energy in this second edition of *The Delicate Balance: An Energy and the Environment Chemistry Module* has been expanded.

Energy as one aspect of a general problem is discussed in the first major section of the module. The need for and shortages of resources are treated, generally, as "the limits to growth." Because we are facing increasingly complex issues and choices, it is important that students learn to recognize and understand some of the basic principles involved in dealing with such environmental concerns.

Our understanding of environmental chemistry has increased tremendously during the past decade. Some "problems" turned out to be of little importance after detailed investigation. For example, it was feared that the nitrogen oxides from supersonic transports (SSTs) would destroy significant amounts of ozone in the stratosphere, permitting dangerous amounts of ultraviolet light to reach ground level. Detailed studies have since shown that nitrogen oxides are unlikely to cause much destruction of the ozone layer.

Many more issues have come to light as we continue to study the environment and try to understand the chemistry-related processes that affect it. Studies of air pollutants, for example, have shown that sulfur dioxide, once thought to be a major "culprit," is not as much of a problem as the particulate materials (especially sulfuric acid) derived from it. In addition, the degradation of visibility by fine sulfate and carbon particles and the acidity of rainfall have become matters of serious concern.

Both knowledge and concern about toxic organic chemicals in the environment, in foods and consumer products, and in industrial plants were intensified during the 1970s. Many pesticides, food additives, hair dyes, food-coloring agents, and other synthetic organic compounds have been found to be carcinogenic, and as a result the use of some has been banned.

The preceding are just a few of the new topics discussed in this revised edition. Many areas are considered in great detail, while other areas that still challenge the research chemist are discussed generally, leaving it open to the inventiveness and creativeness of both teacher and student to explore new topics by using this module as the starting point. Environmental chemistry is a young science that is evolving rapidly. Many changes have taken place since the first edition was published, and no doubt more changes will occur in the future.

To allow for individual preferences, the teaching schedule and time plan are left to the individual teacher. We would like you to remember, however, that a brisk pace is preferable. Because of the modular structure of the IAC curriculum, many concepts are treated several times from different points of view. Therefore an intensive treatment of each concept every time is not necessary. Most teachers allow about seven to eight weeks' teaching time for *The Delicate Balance*.

The module is designed around the basic principles of environmental chemistry, but each teacher will need to set the framework for discussing and investigating new problems as they

arise. To keep your discussions up-to-date you will need to use supplementary materials such as newspapers and news magazines, as well as other scientific sources. The need to keep abreast of changes is a challenge for all of us who teach environmental chemistry. We are rewarded by the excitement, the currency, and the relevance of this constantly changing field of science, making it challenging and fun for both teachers and students.

We do not suggest limiting the use of this module to chemistry courses only. *The Delicate Balance* can be used in conjunction with many other courses in a curriculum. The interdisciplinary approach is one of the unique features of the IAC series.

Special Features in the Student Module

Metric System Le Système International (SI) is used throughout the IAC program. As you work with this module, you may wish to review some points of the metric system as presented in *Reactions and Reason: An Introductory Chemistry Module* (see section *A-8* and Appendix II). There is a metric-units chart in the appendix of *The Delicate Balance* student module that students can easily refer to. In some cases we have had to use English system or mixed units because of the ways that regulations are written; e.g., auto emissions in grams per mile.

Time Machine A feature we call the *Time Machine* appears in the IAC modules in order to show chemistry in a broader context. For some students this may provide a handle on particular aspects of chemistry by establishing the social-cultural-political framework in which significant progress has been made in chemistry. Students may enjoy suggesting other events in chemistry around which to create *Time Machines* of their own.

Cartoons A popular feature of the IAC program is the use of chemistry cartoons. These cartoons give students a chance to remember specific points of chemistry in another important way—through humor. Suggest that your students create other chemistry cartoons for their classmates to enjoy.

Safety Laboratory safety is a special concern in any chemistry course. In addition to including safety discussions and guidelines in the appendix of each student module and teacher's guide, experiments have been developed in a way designed to eliminate potentially dangerous chemicals and procedures. Moreover, each experiment that might present a hazard—such as fumes, corrosive chemicals, or the use of a flame—has been marked with a safety symbol to alert students and teachers to use added, reasonable caution. Caution statements, in bold type, also appear in experiments to specifically instruct the student on the care required.

Selected Readings Articles and books that tie in with the topics discussed in the IAC program have been listed in the appendix of the student module as well as in the teacher's guide. Encourage your students to use this section. Also, make students aware of the importance of keeping up-to-date with current literature in the constantly changing field of environmental chemistry. You may wish to suggest other material that you have found interesting and enjoyable.

Illustrations and Photographs The module is extensively illustrated to provide relevant and stimulating visual material to enable students to relate chemistry to everyday life, as well as to provide material for provocative discussion. In using some of these illustrations, it is not the intention of IAC to endorse any particular product or brand, but only to relate chemistry to life outside the classroom. As you proceed through each section, encourage students to collect, display, and discuss photos and illustrations that provoke further discussion.

Questions and Problems A number of questions and problems have been interspersed throughout the student module, in addition to the questions that are naturally built into the narratives and the laboratory experiments. You will find some of these problems in specifically marked sections in the student module. These questions can be used in a variety of ways as you see fit. They are not planned as tests—remember, the IAC program is designed so that mastery of the content and skills can be achieved through the repeated reinforcement of ideas and procedures encountered by students as they progress through the various modules. (Also see *Evaluating Student Performance* for additional information on evaluation and evaluation items.)

Managing the Laboratory

In the teacher's guide, hints and suggestions are given for managing each experiment in the laboratory. Share as many of these hints as possible with your students to allow them to participate fully in successful laboratory management. Make sure that you rotate assignments so that each student has a chance to experience this type of participation.

Preparations and Supplies Student aides can be helpful in preparing solutions, labeling and filling bottles, cleaning glassware, and testing experiments. Each experiment has been classroom tested, but you should try each experiment to determine any revisions necessary to meet the special needs of your situation or that of your students.

Cleaning Up Involve your students in putting away equipment, washing up glassware, and storing material for the next time it is to be used. Taking care of equipment is part of the responsibilities we seek to foster in the students' outside environment.

Laboratory Reports You may have your own methods of student reporting. We are including some of the suggestions that IAC teachers have found successful in the past. It is helpful for students to keep a laboratory notebook. A quadrille-ruled laboratory notebook with a sheet of carbon paper allows a student to produce two data sheets and report summary copies. One copy of each page can be permanently retained in the notebook, while the duplicate copy can be submitted for evaluation or tabulation.

A realistic view of laboratory work suggests that, in the most fundamental sense, there are no "wrong" laboratory results. All students obtain results consistent with particular experimental conditions (either correct or incorrect) that they establish. Careful work will yield more precise results, of course. Encourage each student to take personal pride in experimental work. If students disagree on a result, discuss the factors that might account for the difference. A student who provides a thoughtful analysis of why a particular result turned out to be "different" (for example, incomplete drying, a portion of the original sample was spilled) deserves credit for such interpretation.

Laboratory Safety The IAC program introduces many new laboratory procedures and activities to students. To use the IAC program safely you should become thoroughly familiar with all student activities in the laboratory. Do all the experiments and carry out all the demonstrations yourself before presenting them to your class. We have tested each experiment and have suggested the use of chemicals that provide the least chance of causing a safety problem in the laboratory. The teacher's guide has many suggestions to help you provide your students with safe laboratory experiences. Have the students read *Appendix I: Safety*. Then conduct a brief orientation to laboratory safety before the students encounter their first laboratory experience in each module. Review, when necessary, and discuss precautions and safety each time a safety symbol appears in the student text. In addition, the *Suggested Readings* in the teacher's guide of *Reactions and Reason* lists safety manuals that give detailed instructions on the handling of hazardous chemicals, disposal of chemicals, and general laboratory safety.

Materials for IAC In light of the need to provide a cost-conscious laboratory program, we have tried to produce a materials list that reflects only the quantities needed to do the experiments with minimal surplus. Thus, the laboratory preparation sections contain instructions for only a 10 to 20 percent surplus of reagents. Add enough materials for student repeats and preparation errors.

Evaluating Student Performance

There are many ways of evaluating your students' performances. One of the most important forms of evaluation is observing your students as they proceed through the IAC program. IAC has developed skill tests and knowledge tests for use with this module. These test items have been suggested and tested by IAC classroom chemistry teachers. You are encouraged to add these to your own means of student evaluation. The module tests are at the end of the teacher's guide.

In addition to the problems and questions incorporated in the student module text and illustration captions, there are suggested evaluation items at the end of each module section in the teacher's guide. Answers to all of the evaluation items are included to help you in your classroom discussion and evaluation.

For information on evaluating student attitude while using this module, see *Reactions and Reason: An Introductory Chemistry Module.*

Module Concepts

OUR ENVIRONMENT: WHAT IS THE BALANCE?

- There is a delicate balance of natural forces in the environment.
- Human activities are placing considerable strain on the balance of nature.
- The demands on the environment can best be understood from the point of view of exponential growth, including the *population explosion* and the demand for resources.
- The limits to growth are imposed by the *carrying capacity* of the Earth.
- Most environmental problems involve chemistry in a central way.
- Chemists have played a vital role in identifying environmental problems and helping to solve them.

THE WATER ENVIRONMENT

- Only a very small fraction of the enormous quantity of water on the surface of the Earth is available for direct use by people and that small supply is endangered by various pollutants.
- A major problem for bodies of water is *eutrophication*. This natural process is greatly accelerated by the dumping of nutrients into water by industries and people.
- Just as in the case of all living species, algae require a balanced diet of chemical nutrients for growth.
- The eutrophication of bodies of water can be controlled by reducing the input of one essential nutrient into the water.
- Most scientists believe that phosphorus (usually present as phosphate) is the nutrient that can be most easily limited.
- Household detergents are a major source of phosphates released into bodies of water.
- *Biological oxygen demand* (BOD) is the amount of oxygen per unit volume that would be required to decompose (oxidize) organic materials in water by biological processes.
- If water with a high BOD is released into thermally stratified receiving water, decomposition can use up virtually all of the oxygen in the bottom waters.
- Most sewage-treatment plants in operation today are designed to remove (or kill) bacteria and reduce the BOD of the water before release, but

they do a poor job of removing nitrogen and phosphorus.

- Phosphates were added to many detergents to combine with hard water ions, thus preventing the formation of precipitates.
- Scientists are seeking substitutes for the phosphates that will perform the same tasks.

TOXIC SUBSTANCES IN THE ENVIRONMENT

- Food chains (or webs) have photosynthetic *producers* at the bottom that convert carbon dioxide and water into high-energy compounds, which supply all of the energy for *consumers* at the higher *trophic* levels.
- Because of the inefficiency in the transfer of energy and nutrients from one level of a food chain to the next higher one, food chains necessarily form pyramids, decreasing in mass about tenfold for each step up.
- The pyramidal nature of food chains causes compounds that are not water soluble yet are nonbiodegradable to have about a tenfold or greater increase in concentration in the bodies of species with increasing steps to higher trophic levels. Consequently, large fish and predatory birds that occupy high trophic levels often have very high concentrations of such compounds.
- Chlorinated-hydrocarbon pesticides (such as DDT) have been very beneficial in the control of insects that destroy crops and spread diseases. Many of these pesticides, however, have been banned or restricted in their use because of harmful effects on people and animals.
- Many synthetic organic compounds in wide use today (including pesticides) have molecular structures unlike those of naturally occurring molecules. Consequently, no enzymes have evolved to catalyze the decomposition of these synthetic compounds which remain in the environment for many years.
- Chemicals that are widely used or those that are planned for use must be tested to make sure they are not carcinogenic or otherwise toxic.
- Tests of chemicals using animal subjects are very expensive and time-consuming, and the observed experimental effects often differ considerably from one species to another. It is therefore necessary to assume that the observed effects of the tested substances are at least as serious for people as for any animal.
- Because of the large number of synthetic chemicals now in use and coming into use each year, scientists are developing laboratory methods that are much faster and less expensive than animal testing for carcinogenic compounds.
- The most widely used test for toxic chemicals is the Ames test, which identifies compounds that are mutagenic. Most mutagenic chemicals are also carcinogenic.
- Experts estimate that up to 90 percent of cancers are caused by "environmental factors," which include chemicals in food and water, exposure to industrially produced compounds, and personal habits, such as smoking.
- As a result of careful testing of chemicals in wide use in recent years, many chemicals have been taken off the market or greatly restricted in their use.

THE AIR ENVIRONMENT

- Concentrations of sulfur dioxide (SO_2) in the air of most cities have been reduced by measures initiated during the 1960s. However, new studies suggest that particulate sulfates, formed from SO_2 by atmospheric reactions of SO_2, are more harmful to people than SO_2 itself.
- Sulfates are a regional problem; they are produced from SO_2 over periods of many hours as the wind carries the air hundreds of kilometers. Therefore, control of SO_2 will have little effect on sulfate levels in the immediate area.
- Automobiles are the major source of carbon monoxide, hydrocarbons, and nitrogen oxides in most areas. Under the influence of sunlight, these substances react to form photochemical smog, characterized by high levels of ozone, aldehydes, ketones, and PAN.
- Although ozone is an undesirable air pollutant at ground level, the natural occurrence of ozone in the stratosphere is vital to life on Earth because it absorbs most of the ultraviolet light in the Sun's spectrum. Significant amounts of ozone in the stratosphere may be destroyed if we continue to release large quantities of chlorofluoromethanes into the air.
- The burning of fossil fuels has released so much carbon dioxide (CO_2) into the atmosphere that the atmospheric concentration of CO_2 has increased significantly during this century. Unless compensated for by some other effect (such

as increases in particle concentrations in the air), continued increases of CO_2 are expected to cause a marked warming of the atmosphere.

- Emissions of carbon monoxide and hydrocarbons (which contribute to the formation of photochemical smog) have been greatly reduced with the use of catalytic converters, but smog levels continue to be high in many areas.
- Although lead-based paint has been removed from the interior walls of most dwellings, exposure to lead continues to be a problem. New studies indicate that excess lead, even at levels too low to cause lead poisoning, can cause decreased mental performance.
- Atmospheric levels of lead are being reduced. Automobiles with catalytic converters cannot use leaded gasoline.

ENERGY: USE AND CRISIS

- About 95 percent of the energy used in the United States today comes from fossil fuels: coal, oil, and gas—all nonrenewable resources.
- The United States uses more energy *per capita* than any other nation.
- The United States is a major producer of oil, but an even greater consumer. In 1978 about 45 percent of its oil had to be imported.
- Many measures have been taken in the United States to conserve energy, especially oil. These measures barely counteract the use of petroleum needed by the three to four million newly licensed drivers each year.
- A critical factor in the conservation of energy is the efficiency of conversion of energy from one form to another. Only about a third of the heat energy released in steam-electric plants is converted into electrical energy at the place where it is used, with much of the balance being lost to the environment as thermal pollution.
- The major conventional energy sources available to the United States over the next several decades are coal and nuclear fission, both of which can cause severe environmental problems if not carefully controlled.

FUTURE SOURCES OF ENERGY

- Geothermal energy is already in use in some areas (such as Iceland and California), and there is potential for developing its use in a number of additional areas.
- The quantity of solar energy falling on land is enormous. It is a diffuse (about 1 kW/m^2 maximum) intermittent source. It is therefore necessary to have energy storage devices for many of its uses.
- Sunlight can be converted directly into electricity by solar batteries, but they are too expensive for most present-day uses. Vigorous research is under way in an attempt to develop solar cells that can be mass produced much more cheaply.
- Many indirect forms of solar energy are being tested for possible widespread use: biomass (converted to alcohol), wind, surf, ocean currents, and thermal gradients in the ocean.
- Almost unlimited energy would be available from nuclear fusion, using the heavy isotope of hydrogen, deuterium, as the fuel. Two schemes, magnetic containment and laser fusion, are under intense study, but both are many years away from practical use.
- The enormous deposits of coal, oil shale, and tar sands in North America could be converted into gaseous or liquid fuels, but there are many problems that must be solved before these *synfuels* can be produced on a large scale.
- Because of the vast capital and resources needed for extensive development of any new energy source, it will probably be many years before any of them are widely used.

WHERE DO WE GO FROM HERE?

- Despite all of the problems that face us, progress is being made to solve them. Certainly our knowledge of the problems and possible solutions is much better than it was when great concern about environmental degradation arose during the late 1960s and early 1970s.
- In recent years, many hazardous materials have been banned or greatly restricted in their uses.
- Many environmental problems result from the *technological* application of knowledge gained from science. This does not mean that we need less science, but we must be more careful in deciding to use new technology on a large scale until its effects are well understood. More scientific knowledge is needed to solve the environmental problems facing our society, especially those involving energy and the environment.

Module Objectives

We have attempted to group module objectives in three broad categories: concept-centered, attitude-centered, and skill-centered. The categories are not mutually exclusive; there is considerable overlapping. The conditions for accomplishing each objective are not given, since they can easily be found in the respective sections in the module. Note also that concept and skill objectives are more specific than those in the affective domain. It is very difficult to classify objectives in this way, but we have been encouraged to do so by classroom teachers, who have helped in this difficult task.

The objectives identified here should provide you with a useful starting point in clarifying your own goals in teaching this module. We encourage you to identify alternative objectives, using this list as a point of departure. *Evaluation Items* to help assess the stated objectives are included after each major unit in this guide. In addition, module tests for knowledge and skill objectives are located in the appendix.

Concept-Centered Objectives *Attitude-Centered Objectives* *Skill-Centered Objectives*

OUR ENVIRONMENT: WHAT IS THE BALANCE?

E-1

- Cite examples of people's interference with nature's delicate balance.

E-2

- Describe problems that result from the population explosion.

E-3

- Distinguish between linear and exponential growth.
- Define and give examples of doubling time.
- List causes of and factors affecting the population explosion.

E-4

- Distinguish between static index and exponential index.
- List environmental effects of increased food and energy production.

E-6

- Describe some of the environmental problems created by our society.
- Cite examples of the types of activities chemists are performing to maintain the *delicate balance*.
- Become aware of the nature of our environmental problems.
- Recognize the magnitude of the task involved in maintaining the delicate balance in our society.
- Become aware of the inherent difficulty in solving any environmental problem without creating another.
- Become sensitive to the environmental problems created by the demands of a super-industrialized society.
- Recognize the role of chemistry in causing and curing pollution problems.

E-5

- Measure energy consumption in everyday life activities.

E-7

- Prepare a series of algae cultures and observe their growth over a period of a few weeks.
- Record observations on a daily or weekly basis.
- Identify some of the major sources of phosphates in the environment.

E-8

- Describe how we obtain our supply of fresh water.

E-9

- List some of the common water pollutants.

E-10, 11, 12

- Describe eutrophication.
- List the factors that accelerate the aging process of a lake.
- Describe thermoclines and their effect on relative oxygen concentrations.
- List a number of steps followed in reversing eutrophication.
- Identify phosphorus as the algae nutrient most easily controllable by people in their efforts to retard eutrophication.

E-14, 15

- Enumerate ions that cause hardness in water.
- List reasons for adding phosphates to detergents.

E-17

- List some possible substitutes for phosphates in detergents and describe the advantages and the disadvantages of each.

E-18

- Describe primary and secondary sewage treatments.
- Define BOD.

E-20

- Describe independent physiochemical treatment (IPCT).
- Clarify the meaning of the term *resource-out-of-place*.

- Become aware of people's dependence on water.
- Adopt ideas that will affect the actions of a citizen concerned about the effect of pollution on other people.
- Understand the consumers' dilemma in view of the phosphate problems.
- Become aware of the problems resulting from waste disposal.
- Recognize the cost and the difficulties involved in cleaning our water completely.
- Realize that the nutrients that cause eutrophication are "resources-out-of-place."

E-11

- Relate experimental results of the effect of nutrients on algae growth to the process of eutrophication.

E-13

- Prepare a standard phosphate solution.
- Measure the amount of phosphate in detergents and water samples by colorimetric means.

E-14, 15

- Distinguish between soft and hard water.

E-16

- Collect water samples for hard-water analysis.
- Standardize a soap solution.
- Determine the hardness of a water sample.

E-19

- Conduct qualitative BOD analyses of water samples.

TOXIC SUBSTANCES IN THE ENVIRONMENT

E-21

- Define *ecosystem, producer, consumer,* and *trophic level.*
- Summarize the principle of the pyramid of life.

E-22, 23

- Describe the process of recycling, and cite reasons why it is desirable that materials be made biodegradable.
- Define and give examples of persistent pesticides.

E-24

- List alternatives to the use of persistent pesticides.
- Relate the pyramidal food chain with pesticide concentrations in certain species of animals.

E-25

- Cite and discuss factors that may cause cancer in different forms.
- List some chemicals that have been found to be carcinogenic.
- Recognize that although pesticides have had many beneficial uses, they have caused some very severe environmental problems.
- Become aware of the carcinogenic effects of many chemicals.

THE AIR ENVIRONMENT

E-26

- Describe the composition and the structure of a "clean" atmosphere and list some of the most common primary and secondary air pollutants.

E-27

- List sources of the pollutant SO_2.
- Become aware of the responsibilities of persons at the levels of local, national, and world citizenship.
- Recognize the adverse effects of CO from any source, including cigarettes.

E-29

- Test the effects of H_2SO_4 on different materials.

E-31

- Measure pH of rainwater.
- Interpret pH values of rainwater based upon local air quality conditions.

- Identify the oxide of sulfur that is an anhydride of sulfuric acid.

E-28, 32

- Cite ways of reducing the SO_2 concentration in the air.
- Indicate why these measures have not reduced concentrations of sulfates on particles.

E-29

- Describe the effects of SO_2 and H_2SO_4 on plants, buildings, statues, and people.

E-30

- Cite some of the undesirable effects of acid rain.

E-32

- Discuss the purpose and operation of an SO_2 scrubber.

E-33

- Compare the sizes of the particles and their effect on light.
- Recognize sources of atmospheric particulates.

E-34

- Give reasons for the changes observed in the Tyndall effect.

E-35

- List the possible effects of air-pollutant particles on the respiratory system.

E-36

- Identify those pollutants that result from the use of internal combustion engines.
- Describe the effects of exposure to elevated levels of CO.

E-37

- Define photochemical smog.
- Describe the atmospheric, topographical, and solar conditions conducive to smog production.
- List some photochemical oxidants.

- Recognize the parameters of environmental problems and determine the salient facts for each problem.
- Mentally "weigh" the progress people have made through technology, with its cause-and-effect relationship to the environment.

E-34

- Observe the physical phenomenon of light scattered by small particles in an aqueous sulfur solution and report accurately the observations made.

E-38

- Learn how to do collections of samples in the field.
- Measure NO_2 concentrations in air samples.

E-40

- Collect soil samples for lead testing.
- Titrate an aqueous sample of a lead-containing solution with EDTA.
- Measure the concentration of lead in soil samples.
- Using chemical methods, detect lead in samples of paint chips.

- Describe the effect of some photochemical oxidants on rubber, plants, and people.

E-39

- State the purpose of tetraethyl lead (TEL) in gasoline.
- Describe the relationship between tetraethyl lead in gasoline and atmospheric lead pollution.
- Note the effects of exposure to high levels of lead.

E-41

- Describe possible solutions to the problem of lead poisoning.
- List sources of lead poisoning other than automotive exhaust.

E-42

- Discuss some of the steps taken to reduce pollution due to auto emissions.

E-43

- Discuss the operation of an internal combustion engine.
- List some alternatives to the standard internal combustion engine, and discuss the advantages and disadvantages of each.

E-44

- Discuss the greenhouse effect.
- Relate a physical property of CO_2 to global temperature changes.

E-45

- Relate the properties of each type of pollutant particle in the atmosphere to its effect on global temperature.

E-46

- Discuss the factors affecting the concentration of ozone in the stratosphere.
- Discuss the problems caused by fluorocarbons.

E-47

- Define (and use properly) common units of energy and power.

E-48, 49

- List energy sources in order of importance and the major uses of the various forms of energy.

E-50

- Propose practical ways of minimizing energy consumption.

E-51, 52, 53

- Discuss some of the undesirable side effects of the usage of specific forms of energy (fossil fuel, electrical, nuclear, etc.).
- Define *fission* and *chain reaction*.
- Describe the process of generation of electricity in a nuclear power plant.
- Discuss the advantages and the disadvantages of nuclear-power generation.

E-54

- Convert Celsius temperatures to the kelvin scale, or vice versa.
- Calculate the theoretical efficiency of steam-electric plants.
- Suggest methods for minimizing thermal pollution of the environment.

E-55

- Cite thermal pollution as one cause for the decreased O_2 content of water.
- Recognize the good and the harmful effects of warmer-than-normal water temperature on marine life.
- Understand the "reality" of our (and future generations') energy crisis.
- Recognize the growth in energy demands and expenditures of our technological society.
- Become aware of the waste involved in some of our industrial processes and of the savings often found in recycling.
- Be sensitive to the dilemmas facing industry and environmental groups with regard to nuclear power production.
- Understand that many activities in technological society have some associated risks and that we must balance the benefits against the risks.
- Recognize that thermal pollution is a constant problem of all steam-electric power plants.
- Be aware that the effects from an environmental change, warmer water, for example, may have ecologically advantageous and disadvantageous effects.

E-50

- Calculate actual energy use of home or school from measurements of fuels and electricity used.

E-55

- Titrate an acid with a base using an indicator.
- Graph evidence of volume relationship of gas solubilities versus temperature variance.
- Interpret a graph of gas solubility versus temperature of solution.

FUTURE SOURCES OF ENERGY

E-56

- Describe how geothermal energy originates and how it can be utilized.
- List the environmental problems of using geothermal energy.

E-57

- Describe how the Sun's energy can be converted to usable energy.
- Distinguish between renewable and nonrenewable sources of energy.
- Discuss the advantages and the disadvantages of solar energy.

E-60, 61, 63

- Describe the role of plants in a solar energy program.
- List and discuss the advantages and disadvantages of gasified coal, gasohol, and other unusual energy sources.

E-62

- Define nuclear fusion.
- Explain qualitatively why nuclear fusion produces so much energy.
- List natural and artificial occurrences of nuclear fusion.
- State the problems of development of nuclear fusion as a power source.
- Compare environmental problems of fusion production with those of other power sources already studied.

E-64

- List some of the factors that should be taken into account before long-term programs are begun to develop new energy sources.
- Realize that by clever, but careful, applications of science and technology we could tap large, new, clean-energy sources.
- Recognize that even "clean" sources of energy have disadvantages.
- Recognize that we can create energy sources that do less harm to the environment than the sources in use today.
- Argue the relative merits of the various clean-energy sources for all our power or for specific uses.

E-58

- Focus a beam of sunlight with a magnifying glass in order to burn a hole in a piece of paper and boil away a drop of water.
- Suggest uses of the Sun's energy.

E-59

- Generate an electric current using a photovoltaic cell.

Teaching The Delicate Balance

Our Environment: What Is the Balance?

The chemistry of energy and the environment has some features that are different from those of more conventional areas of the field. In this opening unit of *The Delicate Balance*, we set the stage for detailed discussions of specific problems in following units. We discuss the delicate balance that exists among various aspects of the environment, and we point out some ways in which people can alter this balance. An important factor behind the effects people have on the environment is exponential growth. Such growth influences both the rate at which we change the environment and the demands we make on renewable and nonrenewable resources, including energy. The involvement of chemistry in these problems is introduced, and the important role of analytical chemists in developing and using methods sensitive enough to detect and study problems of toxic trace substances in the environment is emphasized. Two experiments that require a long time for observations are initiated in this unit; they are to be completed in later units.

As a unifying theme to all the topics covered here, the idea of the Earth as a "spaceship" can be used. This concept can be exploited as a backdrop for each of the major concepts presented in this module: limited size and capacity of the spaceship (population), oxygen supply (air pollution), water and food supplies (water pollution and food production), energy needs, waste disposal, shielding from cosmic radiation, and so on.

E-1 EARTH: ITS DELICATE BALANCE

If we consider the enormous forces and masses of the Universe, the environment at the Earth's surface is actually quite fragile. Most human efforts are miniscule, compared with those of nature. Even the energy released by the largest nuclear weapons is small compared with that created by earthquakes, hurricanes, or even moderate storms. However, human activities have so increased in scale over the years that the balance of natural forces on a local, regional, and even on a global basis can be significantly altered.

Although many environmental problems result from recent technological changes and an increase in the use of energy, degradation of the environment by people is not a completely new phenomenon. Centuries ago, fertile lands in northern Africa and the Middle East were converted into deserts because these lands were overgrazed by herds of domestic sheep and goats. The vegetation was grazed so close to the ground that winds and water severely eroded the topsoil. Also, prehistoric hunting societies probably caused the extinction of some animal species. Lately such changes have become more widespread because of the increased rate of technological development and the tremendous growth of the human population.

Many people mistakenly refer to "ecology" as the study of environmental problems. Actually *ecology*, a branch of biology, is the study of the relationships and interactions among various species of plant and animal life in a portion of the biosphere that may be called an *ecosystem*. Ecosystems can be small, as in the case of an isolated lake or woods, or large, as in the case of an ocean. In a course of this type it would be desirable to incorporate some ecological principles.

Our major venture in this area is the discussion of food chains and the "pyramid of life" in section *E-21*. Another topic that you may wish to point out in this introductory section is that of *redundancy*. A spaceship generally has one or two backup systems for each vital function (such as communication, navigation, oxygen, etc.) so that if the main system fails, the backup systems can be used. This duplication of systems serving the same functions is called *redundancy*. Many important space missions were completed successfully only because backup systems were available to replace faulty primary systems.

A similar redundancy exists in most ecosystems. Most animal species can use more than one type of plant or animal as a major food staple so that if one source fails, the species can survive by making use of alternate sources. Similarly, there

is generally more than one type of predator for each animal species. Thus, if the major predators die, the other predators are able to keep the population of the species from "exploding." If that is not the case, the exploding population may become limited by its food supply.

Although redundancy is an important ecological principle, we have not had the space to include it in the student module. However, it would be an interesting area to explore if you have time. Because of redundancy, the environment is somewhat more resistant to degradation caused by human activities than we might suppose at first glance.

E-2 MAINTAINING THE BALANCE

In this section the problem of maintaining the balance of nature in the face of the population explosion is posed and discussed briefly. However, this problem is so important and so much at the heart of all other environmental problems that it may merit a broader coverage at the discretion of the teacher. The September 1974 issue of *Scientific American* is devoted in its entirety to the subject of population. Other useful references are listed in *Suggested Readings* at the end of this unit.

E-3 THE POPULATION EXPLOSION

In this section the concepts of birth rate, death rate, and exponential growth are presented to give students an understanding of the mathematical principles underlying the population explosion.

The present rate of increase for the world population is 2.1 percent per year, with some countries, such as Libya and Kuwait, having growth rates of 3.9 percent.

As the population increases, all the facilities in the "spaceship" are severely strained, thereby intensifying other problems. Energy supply and food production are just two examples of resources burdened by the population explosion.

You may want to expand on the discussion of the concepts of *exponential growth* and *doubling time*. We suggest that you use the example of the growth of a savings account as follows: Suppose you invest $100 in an account that pays 7 percent per year of *simple interest*. At the end of each year, the bank adds 7 percent of your original investment, or $7, to your account. After ten years your account will have grown to $170; that is, your original $100 plus 10 times $7, or $70. This is an example of *linear growth* because the increase in amount is the same each year. A plot of the value of this type of account over the years is a straight line.

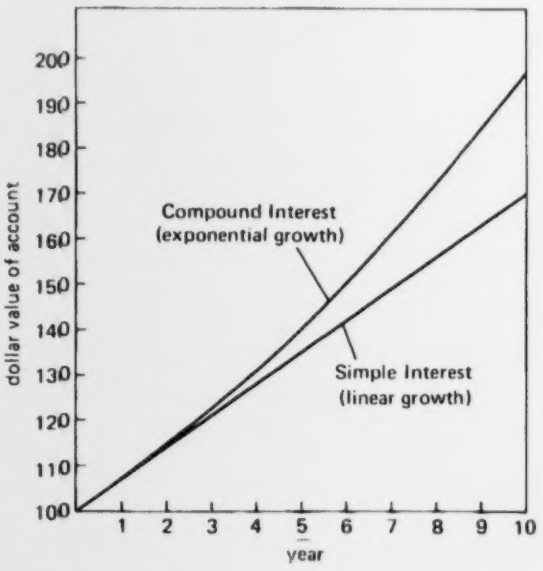
Now, suppose instead that the account draws seven percent interest *compounded annually*. In this type of account, the bank adds $7 to your $100 investment at the end of the first year, just as it does in a simple-interest account. But during the second year, the bank pays interest on $107 (your original investment plus $7 interest) to yield a second-year interest of $7.49. During the third year the bank pays $8.01 interest on $114.49, and so forth. At the end of n years, the value of the account is

$$\$100 \times (1.07)^n$$

where 1.07 is the multiplier for a 7-percent increase. In this case, after ten years, your investment is worth $196.72, clearly an improvement over simple interest. The plot for compound interest curves upward, away from the line for linear growth.

SIMPLE INTEREST VERSUS COMPOUND INTEREST

($100 invested at 7% interest per year)



E-4 THE LIMITS TO GROWTH

Stress the distinction between linear and exponential rates of change as applied to the use of resources. Have students look up and plot the United States or world use rates versus time for various commodities to see which rates are growing exponentially. They can find data in almanacs or in the *Minerals Yearbook* of the United States Bureau of Mines.

All of us contribute to pollution of the environment either directly, by driving automobiles and producing trash, or indirectly, by using the energy and products from power plants and factories.

Miniactivity You may wish to have students make and discuss a list of the ways in which the environment is polluted each day. As the list grows, the students may begin to realize how significant each individual's contribution is to the protection of the environment from pollution.

In teaching about the disproportionate stress our technological nation puts on its surroundings, have the students look over this list of problems and cross out those problems that are *not* typical of underdeveloped nations (such as air pollution caused by airplanes, automobiles, and conditions in large industrial areas). They will learn that, up to this point, a high standard of living has demanded a high price in terms of environmental degradation. Depending on the maturity of the students, you may wish to note that, in exploiting the resources of underdeveloped nations, the industrial nations have left a great deal of the environmental degradation in the countries that have the oil or minerals, often without providing a high standard of living for people of those countries. It will surely not be possible to get away with that in the future.

As the human population moves about in this "spaceship" we cannot help but leave our imprint on everything we do or touch. And the more sophisticated our actions are, the deeper and longer lasting the effect will be.

Many people feel that big corporations cause most of the problems and should pay the bill for cleanup. We would agree that this should be the case in situations where irresponsible pursuit of profits has led to an abuse of our environment. Unfortunately, the costs of fines and cleanup are added to the costs of the products that we purchase. Consequently, we will ultimately pay the bill. Discuss this point with the students and ask them if they would, as consumers, be willing to "pay for the damage."

Miniexperiment Have your students select several items such as newspapers, plastic bags, Styrofoam cups, tin cans, soft-drink cans and bottles, and wood objects. Plan several methods of disposal of each item. Students might suggest these be disposed of by burying them, burning them (this should be supervised), dumping them in water (use a bucket of water), or throwing them in a dumping area (leave them exposed to air and weather). Set up each situation with the students, and ask them to record their observations and draw final conclusions. Some setups will need to be examined, observed, and discussed after several weeks, so begin the activity now.

MINIEXPERIMENT
E-5 ENERGY WATCH

This miniexperiment is designed to make students aware of the amounts of energy that they use in various forms. Although the varous units of energy are not discussed until section *E-47*, it is necessary to start this survey as early as possible in order to average uses over as long a period as possible. A worksheet for this miniexperiment is provided in section *E-50* of this guide.

Have students take initial readings of electric and gas meters and, if their families have motor vehicles, the odometers on such vehicles. If possible, students should have drivers in the family record gasoline purchases to obtain the actual fuel usage; students may then use the odometer readings to determine fuel efficiencies of the vehicles. For those whose families use oil heat, have students enlist adult help in measuring the amount of oil in the tank. Start by dipping a clean wooden stick into the tank to determine the depth and measure the appropriate dimensons on the outside to calculate the volume. If any fuel is purchased during the experiment, it must, obviously, be included in the computation.

Those who live in buildings without individually metered utilities may do a similar treatment of their entire apartment complex or of the school building, if cooperation of the building personnel can be obtained.

You can make this miniexperiment more accurate by keeping a daily record of the outside temperatures. Better still, contact local heating oil suppliers or electric companies to determine the number of heating-degree days or, if done in warm weather, the cooling-degree days during the period. During the course of the miniexperiment, have a group of students who have separately measurable space-heating supplies (such as gas or oil used *only* for space heating) keep a weekly or monthly record of heating energy. Plot this record versus degree days to show how the amount of fuel required depends on the number of degree days. Once the form of this curve is established it can be used in future years to correct all energy uses for a standard seasonal period.

Similarly, students whose homes are air-conditioned by electricity can be asked to establish a relationship between cooling-degree days and extra electricity used for cooling. We suggest that, in most areas, it would be best to use the spring and fall seasons (between heating and cooling periods) as base-line periods to establish an average use rate of electricity for purposes other than air conditioning. Some uses of electricity will increase in winter because of the shorter daylight periods.

Miniactivity Electric and gas meters are usually easy to read. However, some students may have difficulty reading meters that have circular dials. If so, you may wish to draw a series of five dials on the chalkboard and discuss with students the correct method to "read the meter."

(reading = 27185)

Point out that some dials read clockwise and some read counterclockwise. The dials are best read from right to left. When the pointer is between two numbers, record the lower number. When a pointer seems to be directly on a number, record that number only if the dial to the right has passed "zero." If the dial to the right is approaching "zero," record the previous lower number for the dial you are reading. Give students several trial examples to determine if they understand the procedure.

E-6 HOW IS CHEMISTRY INVOLVED?

To illustrate how chemistry is involved in the problems of the environment, you might have the class make a list of these problems and then see how chemistry might play a role in the creation of the problem, the detection of it, or in the solution of the problem.

One of the most vital roles of chemistry in the environment field is that of chemical analysis of environmental samples—atmospheric gases and particles, stream water, food. The sensitivity of analytical methods has increased enormously over the past fifteen years with the introduction and use of techniques such as atomic absorption, nuclear activation analysis, gas chromatography, and mass spectrometry. The detection of many problems, such as the presence of toxic metals in the air, food, and water, has been possible only as a result of these improved methods. In the control of toxic materials, it should be noted that laws and regulations specifying the maximum permitted concentrations of the substances can be written only if there are standard analytical methods available for the measurement of those concentrations.

In fact, many people argue that given the sensitivity of present analytical methods, older legislation such as the 1958 Delaney Amendment of the Food, Drug and Cosmetic Act has become too stringent and has been applied excessively. The Delaney clause states that no food additive, direct or indirect, can be used if it is found to induce cancer when ingested by people or animals. One recent occasion for debate was the use of the Delaney clause in an attempt to ban the sale and use of saccharin. Many people feel that the good achieved by the use of saccharin far outweighs its potential danger as a carcinogen. Others feel just as strongly that it is important to maintain "zero tolerance" of the use of known carcinogens in food, no matter how weakly carcinogenic these substances may be. The concern is that if the "additives people" win their case for the use of one weakly carcinogenic substance, they will then argue for increasing the amounts and kinds of carcinogens that can be used.

You may wish to discuss some of the analytical methods used for various measurements of pollutants or other environmental quality criteria. A good place to start is with the American Chemical Society booklet *Cleaning our Environment—A Chemical Perspective* (Washington, D.C., 1978, paperback). Also, *Analytical Chemistry* publishes a summary of the current status of various techniques each year in the January issue.

ANSWER TO PROBLEM

(Student module page 12)

This problem may best be handled as a class discussion. Ask a few leading questions to get the discussion going. Students will probably have many ideas about environmental problems based on what they have learned from TV or newspapers. Some of their ideas may be inaccurate at this time, but don't worry about correcting them. The point of this exercise is to enhance their awareness of such problems as they go through the module. It might be useful for you to make a few notes on their suggestions and then hold a similar discussion when the module is completed. At that time, bring up some of their original comments and see if they have changed their viewpoints as a result of what they have learned.

EXPERIMENT
E-7 DON'T FEED THE ALGAE

The purpose of this experiment is to observe that the growth of algae can be controlled by limiting one of the required nutrients (phosphate). Since this experiment may require several weeks for growth and observation, start it now. It will be completed in experiment *E-11 How Did Your Algae Grow?*

Concepts In doing this experiment, a student will encounter these important ideas*:

- Phosphate, which is being dumped into the environment in the forms of detergents and fertilizers, is one of the nutrients essential for the growth of algae.
- Phosphate is an essential nutrient in a living organism's diet.

Objectives After completing this experiment, a student should be able to*:

- Prepare a series of algae cultures and observe growth over a three-week period of time.
- Record observations on a daily or weekly basis.
- Identify some of the major sources of phosphates in the environment.

Estimated Time One-half hour for the first day's activity. Then, two minutes for observaton each day for the next two or three weeks. Fifteen minutes for postlab discussion in section *E-11*.

Student Grouping Divide the class into *four* groups.

I. *Complete nutrient group:* This group serves as the control, or standard. All nutrients necessary for the growth of algae are present.

II. *Low nitrogen group:* All nutrients are present; however, the amount of nitrogen present is below that which will stimulate growth.

III. *No phosphorus group:* All nutrients are present except phosphorus.

IV. *Fertilizer group:* Nitrogen and phosphorus are present, but trace elements are absent.

Materials** You will need the following materials for a class of thirty students:

30 18 × 150-mm test tubes
8 pipets (10 cm^3, calibrated) *or* 8 dispensing burets
4 test-tube racks
15 cm^3 algae culture (from pond, aquarium, or supply house)
cotton

Advance Preparation Prepare the stock solutions as follows:

Solution 1

Compound	*Mass (g/1000 cm^3)*
KNO_3	1.0
$MgSO_4 \cdot 7H_2O$	0.12
KH_2PO_4	0.25

Solution 2

Compound	*Mass (g/1000 cm^3)*
H_3BO_3	2.86
$MnCl_2 \cdot 4H_2O$	1.81
$ZnSO_4 \cdot 7H_2O$	0.22
$CuSO_4 \cdot 5H_2O$	0.08
MoO_3	0.02
$Ca(NO_3)_2 \cdot 4H_2O$	59.0
$CoCl_2 \cdot .6H_2O$	0.04

*This statement appears only with this first Experiment, but it applies each time this section appears in an experiment or a miniexperiment unless otherwise noted.

**The *Materials* list for each experiment or miniexperiment in this module is planned for a class of thirty students working in pairs unless otherwise noted. You may have to adjust this to fit the size of your class.

Solution 3

Compound	*Mass (g/1000 cm³)*
Iron(III) citrate ($FeC_6H_{12}O_7 \cdot 3H_2O$)	5.30
Citric acid	5.30

Solution 4

Compound	*Mass (g/1000 cm³)*
KCl	1.0
$MgSO_4 \cdot 7H_2O$	0.25
KH_2PO_4	0.25

Solution 5

Compound	*Mass (g/1000 cm³)*
KNO_3	1.0
$MgSO_4 \cdot 7H_2O$	0.12

Solution 6

Compound	*Mass (g/1000 cm³)*
5-10-10 fertilizer ($N/P_2O_5/K_2O$)	1.77

Solution 7
Prepare the same as *Solution 2*, but substitute $CaCl_2 \cdot 2H_2O$ (36.8 g/1000 cm³) for $Ca(NO_3)_2 \cdot 4H_2O$.

Laboratory Safety Review with your students the standard laboratory safety rules they should be following. Note the safety section in *Appendix I* at the end of the module.

Prelab Discussion Point out that plants, like algae, require a "well-rounded" diet. If certain elements are missing from the diet, plant growth will be hindered. Remind students that careful observations are essential in this experiment.

Laboratory Tips Each student within a group will add the same mixture of nutrients to his or her algae culture. Allowing several students to participate in each of the four groups will help to correct for the variability within each group. After a period of time, a distinct difference between the groups should be evident. Add a few cm³ distilled water every other day to compensate for evaporation.

Students should swirl the solutions each day to ensure that the algae have a fresh supply of carbon dioxide.

Range of Results See experiment *E-11*.

ANSWERS TO PROBLEMS

(Student module page 14)

1. Answers will vary.

2. **a.** $50 \text{ ppb} = 50/(1 \times 10^9) = 5 \times 10^{-8} = 0.05 \times 10^{-6}$, so the answer is 0.05 ppm.
   b. To lower the concentration of Hg in 1 liter of this contaminated water to 2 ppb, we must dilute by a factor of 25, so add 24 liters of pure water to it.

3. **a.** At 5 percent interest compounded annually, the doubling time for any starting quantity is 14 years.
   b. The value of the account today, to the nearest doubling period is

$$A = 100\,(2 \times 2 \times 2 \times \ldots) = 100\,(2)^{14} = \$1\,638\,400$$

4. **a.** In one year the number of people added to the population will be

$$(0.025)\,(6 \times 10^8) = 1.5 \times 10^7, \text{ or } 15 \text{ million}$$

   In 5 years, because of the compounding effect, the number of people to be added to the population will be

$$(6 \times 10^8)\,(1.025)^5 - (6 \times 10^8) = [(1.025)^5 - 1] \times (6 \times 10^8) = 7.9 \times 10^7 = 79 \text{ million}$$

   Using similar calculations, in 10 years the population increase will be 168 million, and in 50 years, the increase from the present number will be 1.46 billion.
   b. Answers will vary.

5. Answers will vary.

6. Answers will vary.

7. **a.** nonrenewable
   b. renewable
   c. renewable
   d. nonrenewable
   e. renewable
   f. nonrenewable

EVALUATION ITEMS

These are additional evaluation items that you may wish to use with your students at various times during the preceding unit. The correct answer to each question is indicated by shading.

1. Match each term in Column II with its appropriate definition in Column I.

Column I

___B___ the increase in a quantity from one period to the next by a fixed fraction of the amount present

___E___ treating or reuse of wastes by converting them into useful products

___A___ the living matter of the Earth

___D___ something that is always being replaced

___F___ the total recoverable amount of a nonrenewable resource

___C___ the time remaining before a resource is used up at a constant use rate

Column II

A. biosphere

B. exponential growth

C. static index

D. renewable resource

E. recycling

F. reserve

2. **a.** Cite two examples of how chemistry can play an important role in causing problems in our environment.

   Sample answer: Many pollutants that result from human activities are not chemically broken down in the environment.

   Consumer products developed through the use of chemical processes have caused problems in the environment.

   b. Cite two examples of how chemistry can play an important role in solving environmental problems.

   Sample answer: developing sensitive analytical methods to detect and study toxic pollutants

   developing methods for converting coal to cleaner gas or liquid fuels

3. In the last few hundred years, people have upset the environmental balance in more ways than any other species since the Earth was formed. List three specific examples of how people have upset the environment.

   Sample answer: fertile lands overgrazed by domestic herds of sheep and cattle have become deserts, the use of fossil-fuel energy has resulted in air and water pollution, synthetic pesticides have endangered certain species of birds

4. **a.** List three renewable resources.

   Sample answer: sunlight, rain, wood

   b. List three nonrenewable resources.

   Sample answer: petroleum, natural gas, copper

5. **a.** What is the difference between the *static index* and the *exponential index?*

   The static index measures the lifetime of a nonrenewable resource in terms of its reserve and *current use rate*. The exponential index, however, measures how long a resource will last at an *exponentially growing rate of use*.

   b. Why might we consider the exponential index to be a more realistic measure of the lifetime of a nonrenewable resource?

   Sample answer: The use rate of most resources increases *exponentially*.

6. Give an example of what is meant by our "disposable" society.

   Sample answer: Many products made of plastic, such as disposable razors, are used a few times and then discarded.

7. **a.** State one way in which you feel you have contributed to the problems in the environment.

   Answers will vary.

   b. State one way in which you feel you have helped in cleaning up or preserving the environment.

   Answers will vary.

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SUGGESTED READINGS

Throughout this teacher's guide we have referred to more detailed writings on specific module topics. Whenever possible, we have referred to articles in *Scientific American*, *Sci-Quest* (formerly *Chemistry*), *Science*, and other journals that are up-to-date and expanded accounts of present knowledge. As general referenes, we would suggest *Chemistry in Modern Perspective* (1975), by G. E. Gordon and W. H. Zoller, and the accompanying laboratory manual, *Experiments in the Chemical Environment* (1976) by W. H. Zoller; G. E. Gordon; J. C. Ingangi; and T. J. Zaucha. The text and laboratory manual cover most topics of this module in more detail and at a first-year college level.

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SUGGESTED FILMS

Choice Stakes. Color, 10 minutes. Modern Talking Picture Service, Inc., 2323 New Hyde Park Rd., New Hyde Park, NY 11040.
Explores the choices and decisions people must make in order to improve the quality of life while they protect the environment.

Earth Resources Technology Satellite. Color, 5 minutes. American Educational Films, Box 5001, 132 Lasky Dr., Beverly Hills, CA 90212.
Food supplies, mineral resources, and shifting coastlines are now brought within view from outer space by this satellite.

Pandora's Easy Open Pop-Top Box. Color, 16 minutes. Film Rental Branch, National Audiovisual Center (NAC), General Services Administration, Washington, DC 20409.
The effects of urbanization are illustrated by contrasting the sound and fury of the city with the serene, unspoiled countryside.

TIC—Index to Energy. Color, 6 minutes. National Audiovisual Center (NAC), Washington, DC 20409.
A story about the Technical Information Center of the Department of Energy at Oak Ridge, Tennessee—a massive effort to help science and industry find solutions to the world's energy problems.

Voices. Color, 28 minutes. Modern Talking Picture Service, Inc., 2323 New Hyde Park Rd., New Hyde Park, NY 11040.
This film is a chronicle of environmental action taken by various citizens' groups determined to have their voices heard by government and industry.

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The Water Environment

This unit opens with a brief discussion of the hydrosphere—that portion of the Earth covered with water—and with brief comments about some ways in which people affect the quality and the availability of water. Several problems are discussed in more detail in later sections. Students are usually surprised to learn that some of our most serious water-pollution problems are caused by the dumping of large quantities of nutrients into the water. The limitations of present-day sewage-treatment plants are discussed, together with possible improvements.

E-8 WATER, WATER EVERYWHERE

The tremendous amount of water used daily by industrial nations accounts for one part of today's water shortage. The addition of pollutants of various kinds to the water supply, especially to those of the highly industrialized nations, puts an additional burden on our overutilized water resources. The increase in human population in areas of the world that do not have abundant water reserves has added another complicating factor to this serious problem. In connection with this last observation, you may wish to remind students that a few years ago the Saudi Arabian government considered towing an iceberg from Antarctica to supply their growing population with a source of clean water. Most of Saudi Arabia's land is, of course, quite arid.

ANSWER TO PROBLEM

(Student module page 17)

Encourage students to make visual observations of easily accessible bodies of water in or near their communities. Have them obtain information from local newspapers and/or magazines. If there is a local historical society or books on local history available, assign several students to obtain old photographs of area waterways. After research has been done, encourage a classroom discussion of their findings.

E-9 THE EFFECTS OF INDUSTRIAL POLLUTANTS

This section can be used as the starting point for a discussion of very recent events that involve the dumping of toxic substances into large bodies of water. Perhaps the two most talked about incidents involve the presence of Kepone in the James River in Virginia, which is discussed in section *E-23*, and the dumping of toxic chemicals into the Love Canal, near Buffalo, New York.

In the first edition of *The Delicate Balance*, more attention was given to the environmental problems caused by mercury and cadmium. These problems are not covered in the revised edition—not because they have been solved, but because so many new problems have arisen in the intervening years. Although some of the big mercury polluters, especially the chloroalkali industrial plants, have stopped dumping large amounts of their wastes into rivers, the sediments of many bodies of water are still heavily contaminated from the past activities. Serious problems may arise at any time if contaminated sediments are dredged. A considerable threat of heavy metal contamination exists in Holland. There, new land is created by damming streams and using sediments brought in by rivers, such as the Rhine, that are polluted by industrial activities in Germany and Switzerland. Food crops grown on this reclaimed soil contain elevated levels of heavy metals and may cause health problems for people who consume them.

E-10 EUTROPHICATION AND OVERFED LAKES

Although we usually emphasize eutrophication in the discussion of Lake Erie (because it is a general water-pollution problem), this is by no means the only factor contributing to the lake's decline. Some of the changes over the past two hundred years may have been natural. The average temperature in that region has risen slightly, and the rise in temperature affects the suitability of the lake for various life forms. However, it seems safe to say that the activities of people (now about fourteen million) have had much more influence than natural causes. People have removed natural ground cover from the land of the watershed and cultivated it. They have dammed streams

that feed it and opened canals (the Erie Canal in 1819 and the Welland Canal in 1829) that allowed new kinds of predators to enter the lake and eliminate some species previously present. They have overfished some desirable species to the point of their disappearance from the lake. Finally, industrial wastes and household sewage have been dumped into the lake, carrying with them many toxic chemicals as well as the nutrients that cause eutrophication. (To illustrate these problems, there is a dramatic picture of the Cuyahoga River in Cleveland that flows into Lake Erie. [See Young, Gordon. "Threat to Man's Only Home." *National Geographic* 138:739 (1970).] This is the famous river that once caught on fire because of the flammable chemicals floating on its surface.) The problems of toxic chemicals are discussed in sections *E-22* and *E-25*.

As discussed in section *E-10* of the student module, the major problem caused by algae is that the dead algae use up oxygen from bottom waters when they decay. One of the major objectives of sewage-treatment plants is to oxidize the sewage as much as possible before release so that organic matter in the sewage will not use up oxygen by decomposing after it is released into a body of water. Although the oxidation of wastes can be done effectively in modern sewage plants, sewage treatment has not been very effective in the prevention of eutrophication of lakes and streams because the nutrients needed for the growth of algae are released—thus defeating one of the major objectives. Perhaps one good solution to the problem of the release of nutrients would be to use them to grow algae in tanks at the sewage plant. The algae could then be collected and perhaps used as food or converted to fuel. As discussed in Section *E-20*, another proposed solution would employ the sewage sludge or partially treated waste water as fertilizer for field crops. Either scheme would prevent the release of nutrients into the water.

EXPERIMENT
E-11 HOW DID YOUR ALGAE GROW?

This is the completion of experiment *E-7 Don't Feed the Algae*.

Range of Results The greatest amount of growth should occur in the cultures of *Group I*. Limited, if any, growth should be observed in *Group-II* cultures. The students might notice that the cultures turn yellow or light brown. This color change is due to the low concentration of nitrogen. No growth should occur in *Group-III* cultures; in fact, several of these cultures may die. Growth should be observed in *Group-IV* cultures, but its rate should not be as great as that seen in *Group-I* cultures. Students should recall that *Group I* was the complete nutrient group; *Group II* lacked nitrogen; *Group III* lacked phosphate; and *Group IV* lacked trace metals (although they are present in very small amounts as impurities in the other reagents). The greatest difference should be noticed between *Groups I* and *III* (with and without phosphorus).

Postlab Discussion Discuss the sources from which phosphates—that is, detergents, runoff from fertilizers, and so forth—enter rivers, lakes, and streams. Such sources increase the concentration of this essential nutrient and cause eutrophication. This postlab discussion leads directly into section *E-12 Putting Algae on a Diet*.

E-12 PUTTING ALGAE ON A DIET

It is important for students to realize that there is nothing magic about phosphorus—it is not a growth stimulant. In order to grow, algae require a "balanced diet" of many elements. We can very crudely represent the photosynthetic production of algae from the major nutrients by the equation

$$106\,CO_2 + 90\,H_2O + 16\,NO_3 + PO_4 + \text{sunlight} \longrightarrow C_{106}H_{180}O_{45}N_{16}P + 154.5\,O_2$$

algae released oxygen

This equation is only approximate—note that we've ignored ionic charges as well as a host of minor nutrients. The formula $C_{106}H_{180}O_{45}N_{16}P$ is not that of a single compound, but represents the gross composition of algae. In terms of numbers of atoms, the balanced diet has a C/N/P ratio of 106/16/1, or a mass ratio 41/7/1.

If the temperature is right and there is plenty of sunlight, algae will continue to grow until they run out of one essential nutrient. *Any essential element can become the limiting element.* In a nutrient solution, the limiting element is the one whose initial concentration relative to that required in the balanced diet is the lowest.

To control the growth of algae, one does not necessarily try to reduce the concentration of the element that is a limiting element prior to the clean-up operation. Suppose that, in some lake, nitrogen is the limiting element (as it apparently is in some cases). Despite that fact, nitrogen might not be the best element to try to control because its sources are generally quite diverse—soluble nitrogen fertilizers and human and animal wastes. Although not initially the limiting element, phosphorus can perhaps be made limiting by control of its release, as its sources are much less diverse than those of nitrogen. In the case of Lake Erie, in particular, the majority of experts now feel that algae growth can be most easily controlled by decreasing the flow of phosphorus into the lake.

In the early 1970s, there was much debate about making phosphorus the limiting element, with the detergent manufacturers being the major opponents of this method. Large-scale experiments, including the Lake Washington study discussed in the student module and other studies on lakes in New York State, have clearly shown that phosphorus can be made the limiting element.

During the 1970s there was some improvement in the quality of water in the Great Lakes. Under pressure by the Federal Government and the states in that area, industrial releases of water pollutants were reduced and only low- or no-phosphate detergents were required in many areas. Funds were provided to improve sewage-treatment facilities at many of the plants around the Great Lakes. Phosphate levels have been somewhat reduced and eutrophication does not occur at its previous level. Levels of DDT have been reduced by 90 percent and Hg concentrations are somewhat lower, although they are still very high. The most serious toxic chemical problem is contamination by polychlorinated biphenyls (PCBs). Many sport fish caught in Lake Michigan contain more than the FDA limit of 5 ppm of PCBs.

EXPERIMENT
E-13 PHOSPHATE IN WATER AND DETERGENTS

The purpose of this experiment is to determine the concentration of phosphate in detergent and water samples by comparison with standard phosphate solutions.

Concept

- Phosphates in detergents and water can be analyzed colorimetrically.

Objectives

- Prepare a standard phosphate solution.
- Experimentally determine the percentage of phosphate in a sample of detergent or water.

Estimated Time Two periods

Student Grouping Four or five students per group

Materials

15 Bunsen burners
15 ring stands and rings
15 wire gauze
2 dispensing burets
15 250-cm^3 Erlenmeyer flasks
15 500-cm^3 beakers
60 18 × 150-mm test tubes
15 test-tube racks
5 g ascorbic acid
1000 cm^3 standard phosphate solution
650 cm^3 ammonium molybdate-sulfuric acid reagent
30 g phosphate type detergent
2 spectrophotometers (optional)
15 spectrophotometric tubes (optional)

Advance Preparation Prepare the reagents as follows.

Ammonium molybdate-sulfuric acid reagent (≈650 cm^3)

1. 15.0 g $(NH_4)_2MoO_4$ in 150 cm^3 H_2O (cool solution in ice bath).
2. Add 250 cm^3 *ice cold* conc. H_2SO_4 to 250 cm^3 of *ice cold* H_2O.
3. Add the *ice cold* ammonium molybdate solution to the *ice cold* sulfuric acid solution (keep in ice bath) while stirring.

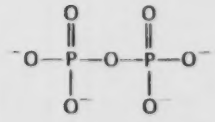
4. When cool, transfer the solution to polyethylene containers.

Phosphate reagent (1000 cm^3)

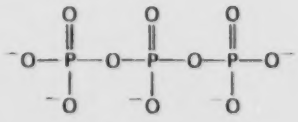
1. 1.0 g K_2HPO_4 dilute to 1000 cm^3
2. Take 10 cm^3 of this solution and dilute to 500 cm^3. This is a 10.91 ppm standard.

Prelab Discussion Ask students to bring in water samples to be analyzed in the lab. If you wish, they may also bring in detergent samples. Assign two groups of students to make up different detergent solutions (500 cm^3 each) for the entire class. This can be done while the other groups are preparing the phosphate standard solutions. Assign groups to make up the four standards called for in each experiment. Three or four pairs of students for each standard will give adequate control for experimental error.

If you are going to use a spectrophotometer, a brief introduction to its proper use would be in order. Point out to the students that even though it makes sense to say that there is a relationship between the intensity of the color and the concentration of phosphate in the sample. It must be determined *empirically*. We must compare the unknown sample with standard solutions either directly or with a spectrophotometer.



pyrophosphate



tripolyphosphate

Phosphorus may be present in the detergent in different forms. Two common forms are sodium or potassium pyrophosphate ($Na_4P_2O_7$ or $K_4P_2O_7$) and sodium tripolyphosphate (STPP) ($Na_5P_3O_{10}$). Sulfuric acid hydrolyzes either compound to the phosphate. The stoichiometry of the overall reaction and formation of the blue complex is somewhat complicated and not very well elucidated. If no spectrophotometer is available, it may be advisable to have students prepare a larger number of standards. This can be easily accomplished by assigning intermediate amounts of the 10.91 ppm standard in step 1 (section *E-12* of the student module) according to the following chart.

Volume Standard (cm^3)	*Volume Water* (cm^3)	*Concentration* PO_4^{-3} (ppm)
40	0	10.91
35	5	9.55
30	10	8.18
25	15	6.82
20	20	5.45
15	25	4.09
10	30	2.73
5	35	1.36
0	40	0.00

Laboratory Safety The normal cautions involved in heating solutions (safety glasses, etc.) should be mentioned. It is advisable to allow the flask containing the boiling solution to cool before it is placed in an ice bath. The drastic temperature change can cause glassware to shatter.

Laboratory Tips The intensity of the color is affected by the length of time the solution is allowed to boil, and so some consistent method of heating must be agreed upon in order to insure comparable results throughout the class. The point at which the first "bump" of boiling occurs is an acceptable standard.

The students must make sure that their flasks are clean before each sample is prepared. Otherwise, contamination will cause considerable error in results. Be sure to rinse glassware with distilled water.

With a spectrophotometer, data can be collected and plotted to obtain an absorption curve for the phosphate standards. This curve can then be used to compare sample values with the standards. A wavelength of 610 nm gives optimum absorption for this experiment.

Range of Results The presence of phosphates produces a bluish color of varying intensity depending on concentration. The suggested concentrations should provide a range of values sufficient to include samples the students will work on. Check detergent packages to determine the normal phosphate concentrations. For a spectrophotometer, the results shown here may be expected for the standard solutions.

ppm PO_4^{-3}	*% Transmittance*
10.91	8
5.46	30
2.73	55
1.37	75
0.68	94

For some detergents, the concentration of PO_4^{3-} may be so large and the intensity of the blue complex so strong that further dilution may be necessary to obtain a point in the central section of the calibration curve. This dilution factor, then, must be taken into consideration in calculating the percentage of phosphate. For example, if the detergent solution is further diluted by a factor of 10, then to calculate the percentage of phosphate, the concentration determined experimentally must be multiplied by a factor of 25 instead of a factor of 2.5.

Postlab Discussion Students may relate the various sources of the water they tested to the amounts of phosphate present and draw conclusions about the environment. The relation of detergents to phosphate content of bodies of water is also material for discussion.

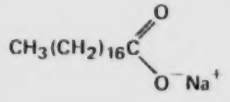
Displaying the standard absorption curve and discussing the spectroscopic techniques used in studying the environment may also be added to the postlab section of this experiment. Further material on detergents follows in the student module, and material in section *E-14* may be included in this postlab discussion.

E-14 WHY PHOSPHATES IN DETERGENTS?

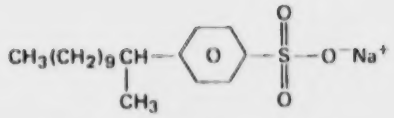
It may help to explain to the students the mechanism of action of soaps and detergents and how the presence of some metallic ions, such as Ca^{2+}, Fe^{3+}, and Mg^{2+}, can interfere with this reaction. (For review, see *Form and Function*, section *O-14*, and *Diversity and Periodicity*, sections *I-34* through *I-36*.)

Bathtub rings are primarily caused by deposits of insoluble calcium and magnesium compounds of the soap anions at the water-level mark. Water softeners are useful in removing these metallic ions from circulation, by different mechanisms.

Soaps are soluble salts of long-chain fatty acids, whereas detergents are salts of sulfonic acids.

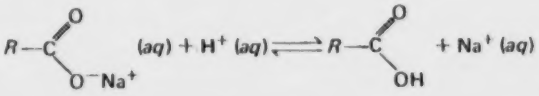


sodium stearate
(a typical soap component)



sodium 2-dodecyl benzene sulfonate
(a typical detergent component)

For soaps to work effectively, they need a nonacidic medium. In any other medium, an insoluble fatty acid will be generated according to the equilibrium.



Soaps must also be used in media free of metallic ions with which they form insoluble carboxylates. Detergents are less susceptible to the presence of both acid and metallic ions.

MINIEXPERIMENT
E-15 RING AROUND THE BATHTUB

This experiment will illustrate the differences between soaps and detergents in hard and soft water and provide an example of the value of a technological advance.

Concepts

- Water hardness interferes with soap action and sudsing.
- Hard water and soap react to form a precipitate. This precipitate can cause a bathtub ring.
- Detergents do not form precipitates in hard water. Because of their chemical structures, detergents produce soluble compounds with hard water.

Objectives

- Make reasonable observations of the results of a simple experiment.
- Observe and record the difference in sudsing action of soap in hard water and in soft water.
- Observe and record the differences between the sudsing action of soap and of detergent in hard water.

Estimated Time Prelab: 15 minutes; Lab: 20 minutes

Student Grouping Pairs

Materials

15 test-tube racks
60 18 × 150-mm test tubes (4 for each pair of students)
100 cm^3 of soap solution *or* have students bring castile soap from home
100 cm^3 detergent solution *or* have students bring detergent from home

Advance Preparation

Soap: Dissolve 0.3 g of castile soap in 100 cm^3 of distilled water. The soap takes several days to dissolve. Be sure the soap is completely dissolved before using the solution in the lab.

Detergent: Dissolve 0.3 g of detergent (any kind) in 100 cm^3 of distilled water. Label the bottle *detergent.*

Hard Water (where needed): Dissolve 2.6 g of $Mg(NO_3)_2 \cdot 6H_2O$ and 2.4 g of $Ca(NO_3)_2 \cdot 4H_2O$ per 100 cm^3 distilled water.

Prelab Discussion Discuss with students the properties of the cloudy solution, the height of the suds, and the particles in the solution.

Laboratory Tips If you make up the soap and detergent solutions rather than have the students bring them from home, your comparisons will be much more uniform and you will have a more controlled experiment.

Range of Results Most students will have the following results.

- Higher suds for soap in soft water than in hard water.
- Cloudy soft water with soap; flakes in hard water with soap.
- A light, cloudy solution with either hard or soft water and detergent.

Some students will compare the height of suds from soap with the height of suds from detergent. Discuss the fact that suds are not effective in cleaning; some manufacturers of detergents put a sudsing agent in their product simply because people expect a detergent to make suds. For soaps, the suds height measures how much of the soap is not tied up in complexes.

Postlab Discussion Compare student data and decide if soaps are an effective cleaning agent in your area.

Answers to Questions

1. Hard water and soap react to form a precipitate that does not participate in the cleaning action of soap. Soap works best in soft water since no unfavorable reactions occur. Both suds level and cleaning action are decreased in hard water.
2. The "bathtub ring" is a precipitate formed by the chemical reaction of soap and hard water. This "ring" is usually deposited at the waterline.
3. A detergent does not form a precipitate in hard water; a soap does.

EXPERIMENT E-16 HOW HARD IS THE WATER?

The purpose of this experiment is to determine the hardness of water by a quantitative method. The exercise in titration gives the students a first-hand exposure to an analytical technique.

Concept

- The concentration of metal ions (hardness) in water can be found by titrating a water sample with a standard EDTA solution.

Objectives

- Collect water samples for hard-water analysis.
- Determine the hardness of a water sample.
- Calculate the hardness of a water sample from laboratory data.
- Standardize a solution.

Estimated Time A brief prelab discussion is necessary to demonstrate the significance of a titration end point. If each pair of students prepares the $blank_{sp}$ standardization of EDTA and two water samples, about 75 minutes total (1½ periods) are needed for lab work. Additional time is needed for calculations and postlab discussion.

Student Grouping Pairs

Materials

30 200-cm^3 (or larger) bottles to collect water samples; plastic soft-drink bottles will work
15 250-cm^3 Erlenmeyer flasks
15 medicine droppers
15 50-cm^3 burets with clamps and stands
15 100-cm^3 graduated cylinders
water samples
distilled water
red litmus paper
2000 cm^3 EDTA solution
1000 cm^3 NH_3–NH_4 Cl buffer
100 cm^3 Eriochrome Black T Indicator Solution
100 cm^3 standard $CaCO_3$ solution

Advance Preparation

EDTA Solution: Make a *stock EDTA solution* by dissolving 32.23 g of Na_2EDTA (disodium ethylenediaminetetraacetate) in distilled water and diluting with distilled water to 1000 cm^3 in a volumetric flask. To prepare the *EDTA solution for the class*, take 100.00 cm^3 (by pipet, buret, or volumetric flask) of the stock solution and dilute to 1000 cm^3 with distilled water in a volumetric flask.

NH_3–NH_4Cl buffer: In a 1000-cm^3 volumetric flask, place 67.6 g of NH_4Cl. *Slowly* add 572 cm^3 of concentrated NH_4OH. Add 4.72 g of disodium EDTA and 3.12 g of $MgSO_4 \cdot 7H_2O$. Dilute to 1000 cm^3 with distilled water.

Standard $CaCO_3$ solution: Put 1.000 g $CaCO_3$ in a 1000-cm^3 volumetric flask. Add about 500 cm^3 of distilled water. Add concentrated HCl until the $CaCO_3$ dissolves. Dilute to 1000 cm^3 with distilled water. Place in dispensing burets for students. The concentration is 1 mg/cm^3 $CaCO_3$ or 1000 ppm $CaCO_3$.

Eriochrome Black T Indicator Solution: Place 0.5 g of *Eriochrome Black T dye* and 4.5 g of hydroxylamine hydrochloride in a 250-cm^3 Erlenmeyer flask. Add 100 cm^3 of 95-percent ethanol. Store in a 250-cm^3 clean, glass bottle. Dispense with an indicator bottle.

Laboratory Tips Have a group of students determine the hardness of rainwater to check the accuracy of the advertising slogan "rainwater soft." To insure exact measurement of the $CaCO_3$ standard, it is best to provide the solution in dispensing burets. You may want to collect class data and organize it so that the students will have a basis for answering the questions at the end of the section.

Range of Results Student results will vary. See the chart given in the student module.

TABLE FOR SAMPLE CALCULATION

Data	*Sample* V_{Sp}	*Dist.* H_2O V_{bl}	*$CaCO_3$ Sol.* V_{std}
Final reading EDTA			
Initial reading EDTA			
Volume EDTA			

$$C_{EDTA}\ (\text{mg } CaCO_3/cm^3) = \frac{C_{CaCO_3}(mg/cm^3) \times 5\ cm^3}{V_{std}\ (cm^3) - V_{bl}\ (cm^3)}$$

$$\text{hardness (mg } CaCO_3/cm^3) = \text{hardness (mg } CaCO_3/cm^3) \times 1000$$

Postlab Discussion If a good range of samples are tested in this experiment, students will be able to draw conclusions about the relative hardness of water taken from different sources. You may want to refer to the role phosphates play in increasing the effectiveness of detergents by reducing the concentration of metal ions in water, which was discussed in section *E-14*. You may explain that using a *blank* is necessary to insure that the hardness of your test sample is not caused by the presence of ions in the buffer, indicator, or EDTA solutions.

In explaining the calculations, you might stress that the first calculation for C_{EDTA} (mg $CaCO_3/cm^3$) finds the relationship of the concentration of the EDTA to a known concentration of $CaCO_3$. The second calculation uses this relationship to find the concentration of a sample containing an unknown concentration of $CaCO_3$.

The calculation for hardness (ppm $CaCO_3$) results from the following steps.

1. $\frac{mg}{cm^3} \cdot \frac{1000\ cm^3}{1\ dm^3} = 1000\ \frac{mg}{dm^3}$

2. $1\ ppm = \frac{1mg}{1dm^3}$

3. $\frac{1\ mg}{cm^3} = 1000\ ppm$

Therefore, the concentration of the $CaCO_3$ standard, which contains 1 g of $CaCO_3$ in 1 liter (dm^3) of solution, may be expressed in mg/cm^3 with the following equation.

$$\frac{1\ g}{dm^3} \cdot \frac{1000\ mg}{1\ g} \cdot \frac{1\ dm^3}{1000\ cm^3} = 1\ mg/cm^3$$

Answers to Questions

1. There should be good agreement among samples from the same source, for example, tap water.
2. There may be variations among samples from the same environmental source depending upon where and when each sample was taken. The distance the sample traveled in contact with soil and rocks after falling to the surface as rain will affect the sample's hardness. The less contact, the "softer" is the water. Hardness also varies according to the types of rocks and soil in the area.
3. Rainwater should have almost no hardness. The only ions it contains are CO_3^{2-} ions (carbonic acid) in equilibrium with CO_2 of the atmosphere. The concentration of CO_3^{2-} is about 10^{-5} M CO_3^{2-}, which would be equivalent to 1 ppm $CaCO_3$, but no Ca^{2+} should be present to combine with the CO_3^{2-} ions.
4. The hardness of a water sample taken from a softener should be essentially zero if the softener is working properly.
5. Various hard-water ions will be deposited on these articles, for example, carbonates and silicates of calcium, magnesium, and iron.

E-17 DETERGENTS: THE PHOSPHATE DILEMMA

If you haven't already discussed complex ions and chelate formation in teaching another module, this section presents a good opportunity. You can also include experiments or demonstrations that illustrate the point—for example, the dissolution of AgCl by formation of $Ag(NH_3)^{2+}$ ions. Polyphosphates (or their replacements) in household detergents are basically needed to form stable, soluble chelates with the hard-water cations and to prevent formation of precipitates by reacting with detergent anions. Chelation has many other applications. One, for example, is the formation of Pb chelates with EDTA in order to remove Pb from the body, a problem discussed in sections *E-39* and *E-40*.

Another important concept is that of acid-base buffers. The second major function of phosphates is to keep the wash water somewhat basic. The difficulty with some of the phosphate replacements, however, is that they are so basic they are dangerously caustic. There is still no "good" solution to the problem of finding replacements for phosphates.

Some of the most imaginative solutions of the problems of phosphates and the disposal of sewage consider the nutrients in sewage to be a resource-out-of-place, a topic discussed in section *E-20* and expanded upon in this teacher's guide in section *E-W2*. Some communities are experimenting with the use of sewage sludge (material that settles out of the waste water during treatment) as a fertilizer and ground conditioner. Mixed with poor soil, the sludge provides an abundance of nutrients, and the organic matter in the sludge becomes humus that gives the soil good texture. In other experiments, partially treated waste water is sprayed on fields to provide both moisture and nutrients.

Despite the attractiveness of these uses of the "resource," a word of caution must be added. Sewage contains not only household wastes, but industrial effluents as well. Depending upon the nature of industries in the community, the industrial waste water, and thus the sewage, may contain sizable quantities of toxic metals such as lead and cadmium. If used as fertilizer for food crops, the sludge or waste water may cause the food to have such high levels of toxic metals that they are not safe for consumption. However, even if this is so, the plan can be salvaged by using the material as fertilizer for nonfood crops, such as trees grown for lumber.

Nitrilotriacetic acid, disodium salt (NTA) was used during the 1960s as a replacement for phosphates in detergents. It was soon withdrawn from the market because of suspected *teratogenicity*: the ability to cause malformation of the developing fetus. Recent studies seem to suggest, however, that NTA is not unsafe after all.

E-18 OUT OF SIGHT—NOT OUT OF CIRCULATION

This section deals with a problem that has only recently come to our attention. As the population increases, more and more waste products must be disposed. In past years a large river often had the ability to dilute and wash down garbage. Eventually, however, the capacity of the body of water is strained to its maximum and the end result is an open sewer. Consequently, the need for sewage treatment develops as more waste is produced.

Chlorine (Cl_2) has been the standard agent used in secondary sewage-treatment plants. It is very effective and economical. However, it is dangerous to handle and it causes the formation of chlorinated compounds that are toxic and/or carcinogenic. In cities such as New Orleans, the drinking water (drawn from the Mississippi River) shows unusually high levels of chloroform ($CHCl_3$), a suspected carcinogen. These levels are higher in the tap water than in the untreated Mississippi water, which seems to point towards chlorination as the source of the problem.

Note that Cl_2 is used in several ways as a disinfectant. As pointed out in the student module, Cl_2 is commonly added to the effluent from sewage-treatment plants just before the water is released. It is also used in water-treatment plants to kill any bacteria in the community water supply. Power plants often use it as a biocide in their cooling water to prevent growth of organisms in the cooling-water system. There is much concern that such additions of Cl_2 to water are causing the formation of chlorinated organic compounds. Other disinfectants have been used or are under consideration for use in these applications, for example, ozone (O_3) and bromine chloride (BrCl). Ozonation is used in Europe to purify water. The chief disadvantages of this method is that O_3 does not remain dissolved in water, whereas residual Cl_2 stays in water until it reaches the tap in your home, thus prolonging the disinfection cycle. Since most organic bromine compounds are at least as toxic as their chlorinated counterparts, it is difficult to imagine that BrCl represents an improvement over Cl_2. Since Cl_2 has been extremely effective in the prevention of disease, we must be very certain that its substitutes are equally as effective. Perhaps a safer approach is to pass the water through an activated charcoal filter before injecting it into the water mains, since charcoal is very effective in removing organic impurities.

EXPERIMENT
E-19 TESTING FOR THE BOD

In this experiment the student learns to make qualitative observations of the rate at which an indicator changes color.

Concepts

- It is possible to grow microorganisms in water with or without air.
- Some indicators do not measure pH.

Objectives

- Collect and store water samples.
- Observe a color change in a turbid solution.
- Have a qualitative understanding of the oxygen requirements of biochemical growth.

Estimated Time Prelab and initial preparation: 1 hour
Each day: 5 minutes for observation

Student Grouping Four or five students per group

Materials

30 sample bottles, 300 cm^3 or larger, with stoppers
powdered yeast
powdered milk
60 18 × 150-mm test tubes
15 test-tube racks
100 cm^3 methylene blue solution
2 1-cm^3 pipets for methylene blue transfer
60 solid-rubber stoppers for 18 × 150-mm test tubes
1 dark room with easy access or similar storage compartment

Advance Preparation

Methylene blue solution: Dissolve 0.20 g methylene blue in 100 cm^3 of distilled water.

Prelab Discussion Little prelab discussion is necessary. However, emphasize the importance of maintaining the aerobic nature of the initial sample. It is suggested that students indicate the source of their samples at this time so that some guidance can be given and a broad range of sample types can then be obtained.

Laboratory Tips Frequent observation of stored test-tube racks and samples by thirty students can prove difficult. A closet with many shelves is best for easy access and quick observation. It may be best for students to observe the samples in shifts: have one student at a time observe all the samples at a specified time, marking those samples that changed color. Then, each

student would need to make only one trip back to the lab. All samples should be properly labeled.

Range of Results Some samples will change color immediately, while others may not change color at all during the incubation period, which could be as long as two weeks. However, most samples will change color within a few days.

Postlab Discussion When all samples are completed, discuss the time necessary to obtain a color change with reference to the source of the sample and the nature of the pollution source.

E-20 LOWERING THE BOD

Aeration is a technique used to supply as much oxygen as needed until the organic material is decomposed aerobically. It has also been employed quite successfully in the restoration of eutrophied lakes.

The problem of removal of nitrogen, phosphorus, and other nutrients is a more serious and costly one. Installation of activated-charcoal filters seems to be very promising. But the cost involved is considerable since these filters must be replaced periodically. EPA studies have estimated that about 70 cities with populations over 75 000 in the United States will have to install these activated-charcoal plants. A new plant for a city of 80 000 would cost between $2 and $5 million, with a concomitant increase of $4 to $11 a year in *per capita* water bills. The final figures will probably be much higher than these estimates given by the EPA.

E-W ADDITIONAL TOPICS INVOLVING WATER POLLUTION (E-W1 – E-W3)

The following are some topics that we had originally wanted to include in the student module, but had to remove because of lack of space. We decided to include them here because we feel that other topics in the student module have a higher priority or are more universal throughout the United States. However, if you are in an area in which one of these topics is especially relevant (acid mine drainage, for example), you might wish to cover it.

MINIEXPERIMENT (Student Optional)
E-W1 pH OF DETERGENTS

Bring a variety of samples of detergent powders from home. Place a few grams of each sample in a separate envelope. If possible, include some nonphosphate detergents containing carbonates or silicates. Dissolve about a gram of each detergent in separate 100-cm^3 portions of water and check the pH of each solution. For highest accuracy, use a pH meter. If one is not available, you can check small portions of each solution with several indicators (whose color changes occur in the range between about pH 8.5 and 12.5) or a universal indicator solution. It might also be of interest to put a gram of sodium carbonate (Na_2CO_3) in 100 cm^3 of water and check its pH. Compare the pH of the sodium carbonate solution and your detergent solutions. The greater the concentration of hydroxide ions in a solution, the higher is the pH. Using the following hydrolysis equation, can you explain why the pH of the sodium carbonate solution is higher than that of pure water?

$$\underset{\text{carbonate ion}}{CO_3^{2-}\,(aq)} + H_2O \rightleftharpoons \underset{\text{bicarbonate ion}}{HCO_3^-\,(aq)} + \underset{\text{hydroxide ion}}{OH^-(aq)}$$

MINIEXPERIMENT (Teacher's Notes)
E-W1 pH OF DETERGENTS

In this miniexperiment the student will determine the pH of a detergent solution.

Concept

- Detergents hydrolyze in water to produce hydroxide ions.

Objective

- Determine the pH of a detergent solution using pH paper, indicator solutions, or a pH meter.

Estimated Time 30 minutes

Student Grouping Individuals, if possible

Materials

30 50-cm^3 beakers
pH paper *or* universal indicator solution
detergent samples
pH meter (optional)
Na_2CO_3 (a few grams) (optional)

Advance Preparation The day before the experiment ask students to bring in small samples (a gram or two) of detergents to use in the experiment. Get as many different detergent brands as possible. A trip to the supermarket will provide a list of possibilities.

Prelab Discussion None

Laboratory Tips How you divide the class for this activity depends on how many different samples you have available and the means you have for determining pH. The more samples you can test, the better will be the basis for comparing their pHs. In order to obtain comparable results, you should decide on the amounts of detergents and water to be used by everyone. A gram of powdered detergent or one cm^3 of liquid detergent in 50 cm^3 of water will be sufficient. One or two students can be assigned to determine the pH of the Na_2CO_3 solution.

Range of Results Commercial detergent pH is between 8.0 and 12.5.

Postlab Discussion One reason why phosphates are put in detergents is because Na_3PO_4 hydrolyzes to produce an alkaline solution of pH 8–10. This is necessary to keep the soap in solution. If the wash water were acidic, the following reaction would occur.

$$CH_3(CH_2)_{14}\overset{\displaystyle O}{\overset{\|}{C}}O^- Na^+ + H^+ \longrightarrow CH_3(CH_2)_{14}\overset{\displaystyle O}{\overset{\|}{C}}OH + Na^+$$

soluble insoluble

In an acidic solution the reaction between the soap molecule and a proton destroys the soap by producing an insoluble, free, fatty acid. Thus all detergents will show pH values greater than 7.

Since there is a great variety of detergents on the market, the postlab discussion might also be used to compare pH values for various products.

E-W2 RESOURCES-OUT-OF-PLACE

Nutrients in water from primary and secondary treatment plants can support the growth of algae. Therefore we could take advantage of the nutrients by passing the effluents into large lagoons designed for the growth of algae as a source of food. Since most people are not particularly fond of eating algae, it would be necessary to stock the lagoon with edible species, such as fish or oysters, that would consume the algae and convert them into marketable foods. Experiments of this type have been successful in a controlled setting at the Woods Hole Oceanographic Institute in Massachusetts.

A more direct use of the nutrients in waste water has been demonstrated at Pennsylvania State University. Partially treated sewage waste is sprayed on groves of nonfood trees. The nutrients fertilize the trees and the soil "cleans up" the water trickling through it.

At the Pearl River Fisheries Research Institute in China, various types of carp are being grown in ponds. Some types feed on waste vegetation from farms, some on phytoplankton, some on zooplankton, and others on human wastes. This experiment in *aquaculture* seems to be doing well.

E-W3 ACID MINE DRAINAGE

Another serious water-pollution problem in some areas is that of *acid mine drainage*. Although the main constituent of coal is carbon, it also contains many impurities, including substantial amounts of iron pyrite (FeS_2). When mining exposes the pyrite to air and water, a series of reactions occur leading to the formation of sulfuric acid. The major reactions can be summarized as follows.

$$2\ FeS_2(s) + 2\ H_2O(l) + 7\ O_2(g) \longrightarrow 2\ Fe^{2+}(aq) + 4\ H^+(aq) + 2\ SO_4^{2-}(aq)$$

In addition, ferrous ions oxidize in air to ferric ions, which use up some of the acid.

$$4\ Fe^{2+}(aq) + O_2(g) + 4\ H^+(aq) \longrightarrow 4\ Fe^{3+}(aq) + 2\ H_2O(l)$$

However, depending on the pH of the solution, some of the Fe^{3+} will *hydrolyze*, that is, react with water to form ferric hydroxide precipitate and more acid:

$$Fe^{3+}(aq) + 3\ H_2O(l) \longrightarrow Fe(OH)_3(s) + 3\ H^+(aq)$$

The reaction of FeS_2 occurs much faster in mines than in the laboratory, apparently because it is sped up (catalyzed) by microorganisms in the mines.

Acid mine drainage is a very serious problem, affecting about 15 000 km of streams, mainly in

the mining areas of Appalachia. Water emerging from the mines has a pH as low as 2.5. This acid solution destroys life in large sections of streams until the acid is diluted by mixing with other water. As the water becomes less acidic, more ferric hydroxide precipitates out, coating everything with a gelatinous, yellow-brown hydroxide.

ANSWERS TO PROBLEMS

(Student module page 39)

1. Algae are chemically beneficial while they are alive because they carry on the process of photosynthesis, producing oxygen and nutrients for higher members of their food chains. When they die, algae are detrimental to other living creatures in the environment because oxygen is used up by their decomposition.
2. Secondary sewage treatment does not completely remove nutrients such as nitrogen, phosphorus, and trace metals. Such chemicals can still contribute to the nutrition of algae. To reduce eutrophication we must reduce the concentration of at least one of these nutrients. Using IPCT is one way of removing nutrients from sewage.
3. Metal scraps, solid waste that can be burned as fuel, and so forth are resources-out-of-place.
4. **a.** The mass fraction of P in STPP is

$$\frac{\text{mass of P in one molecule}}{\text{molecular weight of STPP}} = \frac{3(31)}{368} = 0.253$$

$$0.253 \times 100 = 25.3 \text{ percent}$$

   b. The percentage of P in detergent is

$$(0.35)\,(0.253) = 0.088$$
$$0.088 \times 100 = 8.8 \text{ percent}$$

5. **a.** Mass of STPP added is (0.35) (250 g) = 87.5 g
   b. Changing mass to moles:

$$\frac{87.5 \text{ g}}{368 \text{ g/mole}} = 0.24 \text{ mole of STPP}$$

   c. 60 ppm is equivalent to 6×10^{-5} g $CaCO_3$ per gram of solution. Assuming the density of the solution to be 1 g/cm^3, 100 liters have a mass of 100 000 g. Therefore

$$(6 \times 10^{-5})\,(100\,000 \text{ g}) = 6 \text{ g } CaCO_3$$

   Changing this quantity to moles gives us

$$\frac{6 \text{ g}}{100 \text{ g/mole}} = 0.06 \text{ mole of } CaCO_3$$

   Therefore, in 100 liters of wash water, there are 0.06 mole of Ca^{2+}.
   d. The STPP (0.24 mole in 100 liters) is present in excess by a factor of 4:1 (0.24/0.06).
6. **a.** 25 000 families × 500 (grams/family × week) × 52 (weeks/year) × 35 percent = 2.3×10^8 g of STPP (or 5.8×10^7 g of P)
   b. If tertiary treatment removes 99 percent of P, the amount released will be

$$2.3 \times 10^8 \text{ g} \times 0.01 = 2.3 \times 10^6 \text{ g (2300 kg) of STPP or } 5.8 \times 10^5 \text{ g of P (580 kg)}$$

7. **a.** (15 kg) $(14 \times 10^6) = 2.1 \times 10^8$ kg of P
   b. 2.1×10^8 kg P = 6.8×10^9 moles of P, so the number of moles of O_2 used up will be

$$(6.8 \times 10^9)\,(155 \text{ moles of } O_2) = 1.05 \times 10^{12} \text{ moles } O_2$$

   c. 460 km^3 = 4.60×10^{14} liters
   Total amount of O_2 dissolved will be

$$(10)\,(4.60 \times 10^{14}) = 4.6 \times 10^{15} \text{ mg or } 1.44 \times 10^{11} \text{ moles}$$

   We see that decomposition of algae produced by one year's dumping of phosphorus would use up about seven times as much oxygen as is dissolved in Lake Erie at saturation. Of course, in most areas of the Lake in which bottom waters are mixed fairly well with the surface waters, the consumed oxygen is replaced by oxygen from air dissolving in water. However, this calculation does suggest that in areas with poor mixing (for example, in waters below thermoclines) so much oxygen is used up without being replaced that these areas can become anoxic (devoid of oxygen).
8. Answers will vary.

EVALUATION ITEMS

These are additional evaluation items that you may wish to use with your students at various times during the preceding unit. The correct answer is indicated by shading.

1. Algae are harmful to the ecology of a lake because
   A. they produce carbon dioxide.
   B. they produce chemicals which are poisonous to marine life.

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C. their rapid growth consumes oxygen that fish need to survive.
D. they use up oxygen as they decay.

2. Which of the following human activities has increased the process of eutrophication in Lake Erie?

   A. using the lake as a dump for waste materials
   B. building canals that divert water from the lake
   C. spilling oil from tankers and other ships
   D. allowing factories to use the lake for disposing of toxic chemicals

3. Which of the following substances are usually the easiest to limit in order to control the growth of algae in a lake?

   A. CO_2
   B. nitrogen compounds
   C. phosphorus compounds
   D. sulfur compounds

4. "Hard" water can be caused by carbonates or bicarbonates of

   A. Ca^{2+} C. NH_4^+
   B. Cu^{2+} D. Zn^{2+}

5. Describe the techniques used in primary and secondary sewage treatments. What percentages of the BOD and the suspended solids are removed by each type of treatment?

   Primary sewage treatment involves the removal of large solids by passing the sewage through a screen. Finer solids and grease are collected from the sewage as it sits in a settling tank. This method removes about 32 percent of the BOD and 36 percent of the suspended solids. When primary treatment is followed by secondary treatment, the sewage is passed through aeration tanks where it is treated with aerobic bacteria before being sent to settling tanks. Primary plus secondary treatment removes about 85 percent of both the BOD and the suspended solids.

6. How did the diversion of sewage from Lake Washington in Seattle, Washington to another body of water stop the eutrophication of the lake?

   Sewage diversion reduced phosphate concentration by 80 percent, which led to a reduced algae concentration.

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SUGGESTED FILMS

But For How Long. Color, 27 minutes. Department of the Navy. (Order films from the Naval Education and Training Support Center serving the state in which you live.)
Illustrates ways to combat ocean pollution caused by sewage outfalls, oil spills, and shipboard wastes.

Element 3. Color, 46 minutes. Canadian Consulate General, 1251 Avenue of the Americas, New York, NY 10020.
Supportive of UNESCO's water conservation campaign, this film explores the beauty and the vulnerability of this resource.

Estuary. Color, 28 minutes. National Oceanic and Atmospheric Administration, United States Department of Commerce, Motion Picture Service, 12231 Wilkins Avenue, Rockville, MD 20852.
Depicts the ecological, economic, industrial, and recreational values of estuaries and illustrates the need to plan their use.

The Great Cleanup. Color, 54 minutes. Modern Talking Picture Service, 2323 New Hyde Park Rd., New Hyde Park, NY 11040.
Presents water pollution as an economic and esthetic problem and explores the joint efforts of the United States and Canada to clean up the Great Lakes.

The River Must Live. Color, 15 minutes. Shell Film Library, 450 N. Meridian St., Indianapolis, IN 46204.
Using photomicrography, this scientific study of water pollution illustrates natural purification of rivers and the results of waste overload.

San Francisco Bay. Color, 28 minutes. Association Films, Inc., 600 Grand Ave., Ridgefield, NJ 07657.
A description of the beauty, uses, and problems of world-famous San Francisco Bay.

Tomorrow Is Too Late. Color, 28½ minutes. Canadian Consulate General, 1251 Avenue of the Americas, New York, NY 10020.
Canadian scientists, fishermen, and industrialists work together to conserve and manage fishing grounds.

Water. Color, 28 minutes. Modern Talking Picture Service, 2323 New Hyde Park Rd., New Hyde Park, NY 11040.
This film explores a variety of esthetic and practical uses of water, and emphasizes the need for wiser use and reuse of this resource.

Toxic Substances in the Environment

Although this is a rather short unit, it introduces some of the most important principles in the field of environmental chemistry. The nature of food chains, or webs, is described to explain how some substances become much more concentrated as they move up through the trophic levels. The need for enzymes in biochemical-degradation processes and the persistence of substances for which no appropriate enzymes exist in the environment are discussed. The field of epidemiology is also introduced in connection with a discussion of the idea that mutations by certain classes of chemicals lead to the development of cancers.

E-21 THE PYRAMID OF LIFE

It is important for students to understand the "pyramid of life." Although the concept is a principle of ecology, chemists must know something about it in order to understand the mechanisms by which some toxic substances (such as DDT and mercury) become concentrated in species near the tops of food chains. The reason for the pyramid is that, because of the inefficiency with which energy and nutrients are transferred from one trophic level to the next higher one, individuals of the higher-level species must consume about ten times their own mass or more of species from lower levels during their lifetimes.

Although we have introduced the pyramid mainly as background for the discussion of toxic substances, it also has very important implications for the world's food supply. Because of space limitations, we have had to remove the discussion of this critical problem from the student module.

The pyramid of life is involved in the world food supply in the following way. People of the developing nations take most of their food from the first trophic level, that is, from grains or other plants (the producer organisms). People of the highly developed nations consume much of their food from the second trophic level, that is, from cattle, hogs, sheep, and other animals that consume the producers. Because of the inefficiency of nutrient and energy transfer, we lose about 70 to 90 percent of the nutrients and energy available at the first trophic level by using the grain to feed animals, which we then eat. Thus, persons whose diets include large amounts of meat must be supported by a much larger mass at the first trophic level than those who mostly consume grain directly. If the vast populations of the non-technological nations had diets similar to those of highly technological nations, this inefficiency in

energy utilization would cause large-scale starvation; there are not nearly enough plant products available to support all the feed animals required for this kind of diet.

A great deal of research is being done on the production of protein by bacteria. In some cases cellulose is used as the substrate, or raw material. Researchers in the Soviet Union seem to prefer an oil substrate instead, while their Japanese counterparts use ethanol as the substrate.

E-22 ALIEN SUBSTANCES IN THE ENVIRONMENT

The main point to teach in this section is the notion that, except for ionic reactions, very few chemical reactions proceed in biochemical systems unless an enzyme is available to catalyze the reaction. Over the billions of years that life has existed on Earth, biological species have evolved enzymes to catalyze the breakdown of nearly all naturally occurring molecules. But the many synthetic chemicals now in circulation have not been present long enough for biological organisms to have evolved enzymes for those chemicals. The only synthetic chemicals that can be removed from the environment by biodegradation are those whose structures are so similar to naturally occurring biochemicals that they can be broken down by the same enzymes that catalyze the degradation of the natural biochemicals.

You may wish to perform an experiment involving enzymes. Refer to *Molecules in Living Systems: A Biochemistry Module*, miniexperiment *B-31 Enzymatic Digestion of Protein*.

ANSWER TO PROBLEM

(Student module page 44)

Answers will vary, but encourage students to think of the problem of plastic containers, plastic wraps, and so forth. Note that some nonbiodegradable substances can be recycled.

E-23 PESTICIDES—WHERE DID THE BIRDS GO?

DDT and similar pesticides were "too successful." However, we should not minimize their great value during and since World War II in preventing the spread of diseases by insects (such as malaria spread by mosquitoes) and in controlling insects that would otherwise have destroyed vast food crops. In view of these successes, the uses of DDT and other chlorinated hydrocarbon insecticides increased enormously in households, on farms, and in wide-scale spraying campaigns designed, for example, to eliminate flies (which were then thought to carry the dread disease polio) from large areas.

One major problem of pesticides is that they are usually nonspecific, that is, they kill not only the "target" pest, but many other species such as birds, fish, cats, and, ironically, often the predators that had previously been keeping the population of the target insect within some kind of bounds. For example, in one test, plots of trees were sprayed with various insecticides. It was later found that those sprayed with DDT were infested with red mites. Later, it was discovered that lady beetles were absent from the DDT-sprayed plots. Refer to the article by G. McIntire, "Spoiled by Success." *Environment* 14(6):14 (1972).

Another problem with pesticides is that insects often become resistant to a particular one, especially when it is applied over wide areas in attempts to remove the insect from the area entirely. In the population of any species there are great variations in resistance to a particular pesticide. Some members of the species have unusually high resistance, in part because of mutations, or "changes," in the genetic code. These mutations are caused by such things as gamma rays striking the genetic material of the insect's ancestors.

When insects are subjected to massive spraying of a pesticide, perhaps 99 percent of them may be killed. Those that survive are the 1 percent having the highest resistance. Future generations of the insect species will all be offspring of these survivors and most will have much greater resistance to the pesticide than the population prior to spraying. Therefore, it is necessary to use greater doses of the insecticide or switch to a more powerful type to control the insect population. (Similar effects happen with disease-causing agents. When penicillin was first used, it was highly effective against venereal diseases. It is becoming less so each year, however, as penicillin-resistant organisms cause more venereal disease.)

At present we do not really know what long-term effects, if any, will result from the sublethal amounts of DDT stored in our bodies. Since excessive DDT concentrations in female birds affect the production of sex hormones, we must be concerned about the possibility of a similar effect in our bodies.

Even though DDT was banned in the United States in 1972, it is still being synthesized in large quantities for use abroad. In 1975 the United States exported over four million metric tons of DDT.

In order to attack DDT-resistant insects, more powerful insecticides have been developed, such as endrin, heptachlor, chlordane, dieldrin, and parathion. These substances present a very serious health hazard to anybody coming in contact with them, such as farmers, manufacturers, or their unlucky neighbors.

Many of the chlorinated-hydrocarbon pesticides have been banned for most or all uses in the United States, including aldrin, benzene, hexachloride, chlordane, dibromochloropropane (DBCP), DDT, heptachlor, Kepone, and Mirex. Many are carcinogenic and some cause birth defects. One of the most controversial was the herbicide 2,4,5-T, which contained minute concentrations of a dioxin impurity—2,3,7,8-tetrachloro-dibenzo-*p*-dioxin (TCDD)—perhaps the most toxic organic chemical known. (It can kill animals at levels as low as 10 parts per *trillion*.) It was the release of a few kilograms of TCDD from an industrial plant in Seveso, Italy in 1976 that caused the entire town to be evacuated; this town has remained abandoned ever since!

The ban on most uses of 2,4,5-T was instituted because it was found that an abnormally high rate of miscarriages occurred among women of Alsea, Oregon following large-scale spraying of the herbicide in that area by helicopters. In addition, many of the 2.8 million Vietnam veterans were exposed to "Agent Orange," which consisted of about equal amounts of the herbicides, 2,4,5-T and 2,4-D. Thousands of metric tons of Agent Orange, containing hundreds of kilograms of TCDD, were sprayed in Vietnam as a defoliant. There has been a considerable increase in the incidences of liver cancer in residents of Vietnam, and hundreds of Vietnam veterans have experienced incidences of skin problems, nervous disorders, and certain types of cancer.

E-24 SHALL THE BUGS TAKE OVER?

Students sometimes become so zealous about nature and its preservation that they would willingly toss out the advances of science and technology and exist "in harmony with nature." We should perhaps emphasize that there are now so many of us that we must use every bit of our knowledge to prevent massive starvation and disease, and to try to provide at least a minimal standard of living for everyone on Earth. If nature were left entirely to its own devices, there would probably soon be a lot more bugs and a lot fewer people on Earth. Despite the environmental damage brought on by technological advance, developments in medicine and nutrition have increased average life spans in the United States.

As noted in the student module, some very imaginative new methods for the control of insects are under development. In view of past mistakes, great care is being exercised in the testing and application of these methods. One of the most interesting techniques is that of using sex attractants. Such agents have the advantage of being specific to the target insect species. Furthermore, they do not have to be sprayed all over the area, but are simply placed in insect traps. In initial tests, the attractants have been quite successful except when the target insect population is so high that the scent of the attractant from the insects overwhelms that from the traps. In that case the insects are so prevalent that they have no difficulty in finding mates.

Recently a new philosophy of pest control known as "integrated pest management," or IPM, is gaining more attention among farmers in the United States. This method incorporates crop rotation, sophisticated insect traps containing sex attractants, and computer analysis of insect life cycles. With this system, chemical pesticides are used only as a very last resort.

E-25 CARCINOGENS IN THE ENVIRONMENT

The presence of carcinogens in the environment is perhaps the "hottest" topic in the book. Because of the Ames test and because more careful epidemiological studies are now being done, we have become much more aware of the carcinogenic and/or mutagenic properties of many chemicals. Some students may have the idea that

everything is carcinogenic. Indeed, some people are now saying that "if you ingest too much of anything, even water, you will die." This statement is true, but even if you do die of excessive ingestion of chemicals you probably won't die of cancer: of the 7000 or so chemical compounds that have been tested, only about 500 are carcinogenic.

There is much concern that many of the synthetic chemicals that have come into wide use since World War II will cause a large increase in the incidence rates of cancer. The absolute death rates from cancer have increased substantially in recent years, partly because many other diseases that would have killed people before they developed cancer have been controlled with modern medicine. However, even after taking this factor into account, the rates at which people develop cancers have still increased. Thus, vigorous efforts are being made to identify carcinogenic substances and to eliminate them from our environment.

Miniactivity You might have students clip newspaper articles concerning products being tested for carcinogenicity or products that are under suspicion of being carcinogenic or otherwise toxic. Have them list the products involved, determine their compositions, discuss methods of disposal, and suggest products that could be used as substitutes.

Some major classes of carcinogenic compounds include many chlorinated or brominated organic substances, dyes, benzene and the polynuclear aromatic hydrocarbons, and nitrosamines. These findings have caused great disruptions in the chemical industry, not only by limiting the chemical products that may be produced, but also by requiring much more careful control of workers' exposure to hazardous chemicals. These findings have also caused many changes in chemistry laboratory experiments, since the carcinogenic compounds such as benzene and chloroform, once common laboratory reagents, can no longer be used.

There is quite a bit of controversy about the statement that "80 to 90 percent of all cancers are due to local environmental factors." This does *not* mean that these cancers are caused only by carcinogens floating around in the air and the water. "Local environmental factors" include personal habits such as smoking or drinking, foods eaten, exposures to carcinogens in the workplace, the use of various consumer products, and lifestyle factors.

The big debate is over the percentage of cancers caused by exposures to carcinogens in the workplace. It is known that workers in the asbestos, uranium mining, vinyl chloride, and rubber tire industries have suffered work-related cancers. A 1978 study by the United States Department of Health, Education, and Welfare predicted that 20 to 40 percent of the cancers that will strike Americans over the next several decades will result from workplace exposure to carcinogens. Other experts feel that these predicted figures are much too high.

A huge battle has been raging over saccharin, the artificial sweetener. Extensive testing has shown it to be a very weak carcinogen. If we were to express its strength as a carcinogen with the number *one*, the strength of aflatoxin B, a carcinogen formed naturally by certain molds on peanuts and grain, would be about *one million*. However, by the rules of the Delaney clause, saccharin should not be used as a food additive. Many people have argued that for certain classes of the population (diabetics and severely obese people), the benefits of saccharin outweigh the risks. Apparently, saccharin will be left on the market, but products containing saccharin will have warning labels on their packages.

Among the environmental contaminants of greatest concern are the polychlorinated biphenyls (PCBs). These compounds are chemically quite similar to DDT; both are chlorinated hydrocarbons with low water solubilities, low vapor pressures, and strong resistance to chemical or biological breakdown. Thus, both persist in the environment and are concentrated in species at the high trophic levels. PCBs are carcinogenic, and they also cause skin rashes, birth defects, and liver damage. They cause other problems similar to those caused by DDT: for example, eggshell thinning in birds.

It was not surprising to find that DDT was widely dispersed in the environment since it was sprayed over large areas. But PCBs were not intentionally used in "dispersive" ways: they were used mainly as the working fluids in hydraulic systems, as coolants and insulators in

electrical transformers, as insulation on household wiring, and in noncarbon reproducing paper. PCBs were first discovered in large amounts in the environment by a Swedish scientist, Dr. Sören Jensen, who was using gas chromatography to detect DDT and its residues in the environment. In his studies, Dr. Jensen found additional peaks in the spectrum that he later identified as PCBs. These compounds have since been found throughout the environment, occurring at levels of about 1 ppm or greater in many species. Fish from many areas contain more than the 2 ppm safety limit set by the Federal Drug Administration. Because of local industries, the Hudson River and Lake Michigan are especially heavily polluted with PCBs.

One of the worst environmental disasters in recent years involved polybrominated biphenyls (PBBs), chemical compounds similar to PCBs but which have bromine instead of chlorine. If a chlorinated organic compound is toxic, it often happens that the corresponding brominated compound is more toxic, which is true in the case of the PBBs. In 1973, a chemical supplier in Michigan accidentally included ten to twenty "50-pound" bags of PBB (intended for use as a fire retardant) in a load of cattle-feed supplement. The PBBs were mixed into the feed, which was sold to farmers. A great number of cattle became sick and many died. It took eight months of investigation to determine the cause of the problem. By that time, many farms were contaminated with PBBs. About 30 000 cattle and many other contaminated animals had to be destroyed. Although PBB contamination has been blamed for many illnesses of people who consumed food contaminated by PBBs, the long-term extent of human problems has not been clearly established.

The chemical industry has complained about "over-regulation by Washington." A story involving hair dyes illustrates the issues that are involved. Tests by the National Cancer Institute have established that seven of the thirteen commonly used compounds in permanent hair dyes are carcinogenic. The government is powerless to ban most of them from further use because of a 1938 law that exempts "coal-tar products" from regulation. Although the Federal Drug Administration could not ban these dyes, they proposed a regulation in January 1978 that would require manufacturers to add a warning similar to those on cigarette packages to packages of hair dyes that contain the carcinogenic compounds. One of the compounds involved is 4-methoxy-m-phenylenediamine sulfate (4-MMPD). Instead of using the warning label, some manufacturers have replaced 4-MMPD with the corresponding ethyoxy compound (4-EMPD), which has not been tested. These two compounds are almost chemically identical. It is very likely that 4-EMPD will be found to be carcinogenic. The Ames test has shown 4-EMPD to be mutagenic, but animal tests to determine if it is carcinogenic have not been completed. Furthermore, the possibilities for such substitutions are almost unlimited.

Another enormous problem that arose during the 1970s was the leakage of toxic chemicals from dumps of chemical wastes into the surroundings. One very serious incident took place in the Love Canal area of Niagara Falls, New York. A chemical company used the partially excavated Love Canal area as a dumping site for over 18 000 metric tons of chemical wastes before filling it in in 1953. A school and about 100 houses were built on the land during the late 1950s. During the 1970s, chemicals started to come to the surface of the dump site and to leak into basements of some of the houses in the area. Investigations have shown the presence of more than 300 compounds, many of which are mutagens, carcinogens, or teratogens. In 1978, an area that included the school and 235 houses was abandoned; the houses were boarded up, and the area was fenced off. Cleanup efforts were initiated, but it is doubtful if it will ever again be safe to occupy the houses.

The Love Canal incident is symptomatic of a much greater problem. Millions of metric tons of chemical wastes are thought to be buried or dumped in various areas throughout the United States. The problem has been compounded by many chemical dumping companies that have operated outside, or at the very edge, of the law. It is expensive to dispose of toxic wastes properly, but by using "quick and dirty" methods of disposal, such unscrupulous companies were often able to underbid legitimate disposal companies and obtain contracts to dispose of wastes from large chemical plants. Usually such companies kept few or no records of their operations, so authorities are now unable to locate many of the dumping areas. Even if such companies did vio-

late the law, many went out of business years before their violations became evident, leaving no one to be prosecuted.

A great deal of effort and huge amounts of money will probably be required over the next several years to identify these toxic chemical dumping sites and to clean up those that are releasing their contents into the surrounding environment.

The Toxic Substances Control Act (TSCA), a landmark piece of legislation, was passed by Congress in 1976 and signed by President Ford. This law requires chemical manufacturers to give the Environmental Protection Agency (EPA) 90 days' notice before marketing a new chemical product or before marketing an old chemical product for a new use. The manufacturer must supply all information known about the product, including results of toxicity tests. The EPA examines the data and may require further testing before approving a product for market. Or, the agency may decide not to release the product.

ANSWERS TO PROBLEMS

(Student module page 54)

1. Divide mass (in kg) by mass of food consumed per day (in kg).
2. Since only 10 percent of the nutrients and *all* of the pollutants are transferred to the next higher trophic level, the pollutant concentration increases at every step by a factor of 10.

1st trophic level	10 ppb
2nd trophic level	100 ppb
3rd trophic level	1000 ppb (1 ppm)
4th trophic level	10 ppm
5th trophic level	100 ppm

3. When epidemiological studies are complete, researchers select the lowest incidence rate of a particular cancer as the *natural rate*. This rate is usually between 10 and 20 percent, depending upon the type of cancer under study. Additional cases are assumed to be caused by local environmental factors.
4. **a.** animal experiments
   b. short-term testing, such as the Ames test
   c. epidemiological studies, in which cancer rates are calculated for different population groups and for workers in various industries
5. Tests for carcinogenic activity of food additives are based upon probabilities. If a small group of animals is fed high dosages of a suspected carcinogen, and some of these animals develop cancer, scientists can extrapolate this finding to the human population. Thus, findings for animals based upon high dosages given over a short period of time can be used to predict that a certain percentage of people exposed to the substance in lower dosages over a longer period of time will develop cancer. Since some cancers take 20 or 30 years to develop after initial exposure to a carcinogen, these studies are a reasonable method of determining long-range probabilities.

EVALUATION ITEMS

These are additional evaluation items that you may wish to use with your students at various times during the preceding unit. The correct answer is indicated by shading.

1. Which statement is true about the food chain that extends from microscopic animals to mammals?
   A. The food requirement of the producers is greater than that of the consumers.
   B. The producers at the bottom of the chain must supply many metric tons of food for the consumer animals in the middle. This provides the consumer animals in the upper trophic levels with a small amount of food.
   C. Mammals consume their weight in food daily.
   D. The ocean is the ultimate source of food energy for our planet.
2. In a typical aquatic food web, which step will contain the largest concentration of DDT (expressed as ppm)?
   A. aquatic birds
   B. fish
   C. phytoplankton
   D. water
3. Which one of the following products is nonbiodegradable?
   A. cardboard
   B. cellulose
   C. cotton fabric
   D. polyethylene
4. Which of these statements regarding nonpersistent pesticides is correct?

A. They are nontoxic to humans who come in contact with them.
B. They are not yet in use by farmers.
C. They break down in the environment within a few days or weeks after application.
D. They are no longer in use, since they were found to be ineffective in controlling insects.

5. Which statement regarding carcinogenic substances is correct?
A. A positive Ames test proves that a compound is carcinogenic.
B. Not all carcinogenic substances found in nature are a result of human activities.
C. A carcinogen present at a 1 ppb level can be assumed to be harmless.
D. The most widely used method of checking for carcinogenic chemicals is to determine the actual structure of the substance under question.

6. "We must be careful to weigh the positive dangers of change against the benefits we hope to achieve." Discuss this statement with regard to the use of synthetic chemicals in the environment.

Answers will vary; see sections *E-22, E-23, E-24,* and *E-25* for examples of the dangers and/or benefits of the use of synthetic compounds.

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SUGGESTED FILMS

Endless Chain. Color, 28 minutes, United States Department of Energy, Film Library, P.O. Box 62, Oak Ridge, TN 37830.
Account of an ecological study aimed at promoting harmony between the individual and the environment.

Green Survival—A Series of Small Steps. Color, 12½ minutes. Association Films, Inc., 600 Grand Ave., Ridgefield, NJ 07657.
A dramatically illustrated portrayal of steps that can be taken to increase positive human contact with nature despite the barriers associated with creating a modern society.

No Turning Back. Color, 27½ minutes. United States Department of Energy, Film Library, P.O. Box 62, Oak Ridge, TN 37830.
Focuses on several scientists doing ecology research, and explores visually the environments in which the researchers are involved.

BEST COPY AVAILABLE

Pollution Solution? Color, 14½ minutes. National Aeronautics and Space Administration. (Please order films from the NASA Regional Film Library serving the state in which you live.)
A discussion of ways in which the Landsat Satellite's remote sensing capabilities may aid in solving environmental quality problems.

Two for Fox. . .Two for Crow. Color, 17 minutes. Association Films, Inc., 600 Grand Ave., Richfield, NJ 07657.
Discussion of the ways in which agricultural chemicals, properly used, enhance the environment.

Undersea Oasis. Color, 29 minutes. Shell Film Library, 450 N. Meridian St., Indianapolis, IN 46204.
An investigation of the development of a new, aquatic, ecological environment—artificial reefs.

The Air Environment

We start this unit with a brief discussion of the natural conditions of the atmosphere. We then cover a wide variety of air pollution problems, both local and global in scope. Local air pollution problems include those involving sulfur dioxide (SO_2) and the sulfates, particulate matter, photochemical oxidants and lead, and acid precipitation. Global problems include the greenhouse effect, the effects of fine particles in the global circulation, and chemical threats to the ozone layer in the stratosphere.

E-26 AIRING THE PROBLEM

As discussed in the student module, air pressure, p, drops off with altitude, z, in an approximately exponential fashion, that is, according to the equation

$$p = p_0 e^{-z(\text{km})/8}$$

where p_0 is the pressure at ground level. By putting $p = p_0/2$ into this equation, you can see that $z_{½} = 5.5$ km, the altitude over which the pressure drops to half of its initial value. Because of the nature of exponential growth and decay curves, it doesn't make any difference at which altitude you start. The factor-of-two fall-off of pressure occurs with each 5.5-km increase in altitude. This equation gives only approximate values because it assumes a constant temperature, but it is reasonably accurate up to about 20 km.

Although there are large variations in the concentrations of many of the minor and trace constituents of the atmosphere with altitude and location, there are very small variations in the concentrations of the major constituents: nitrogen (N_2), oxygen (O_2), and argon (Ar). These gases are still the major ones, making up about 78, 21, and 1 percent, respectively, of the air by volume (or mole fraction).

Since the early 1970s, there have been some changes in the categories in which atmospheric emissions are listed and in air-quality standards. "Volatile organic compounds" is a more inclusive category than "hydrocarbons," which was previously listed. Methane emissions are not included in this category because (1) methane is much less reactive than other organic compounds, and (2) vast quantities of methane are produced by natural processes, for example, the decay of vegetation in swamps. This is not to say that methane is not important in atmospheric chemistry: on a worldwide basis, the oxidation of methane is a major source of carbon monoxide (CO).

The EPA added an air standard for lead (Pb) in 1978. Except in areas near industrial sources (for example, sulfide ore smelters), cities should have little difficulty meeting the lead standards, since lead concentrations are dropping. This is due to an increase in automobiles equipped with catalytic converters that require unleaded fuel.

During 1979 the original air-quality standard for "photochemical oxidants" was replaced with a standard for "ozone." Photochemical oxidants, the compounds in the old category, were defined as all species capable of oxidizing I^- to I_3^- when air was bubbled through a solution of KI. Since ozone (O_3) probably accounts for 90 percent or more of the photochemical oxidant concentration in most areas, this category change may not seem very important, but there are subtle differences. First, the change makes it possible to make direct use of the readings from real-time instruments that measure O_3 concentrations from chemiluminescence generated when O_3 reacts with ethylene or from spectroscopic absorptions. Second, it should be recognized that, although O_3 attacks rubber products and some forms of vegetation, it is probably not the major chemical species responsible for the adverse effects on health associated with smog. Those effects are more probably caused by aldehydes, ketones, peroxyacyl

nitrates (PAN), and many other organic constituents of smog. Since these compounds are difficult or impossible to measure accurately by the use of monitoring networks, the measurement of photochemical oxidants has been taken as a sort of general indication of smog levels. Although the measurement of O_3 alone is more clear-cut, basing the air-quality standard on O_3 alone may make the control of smog more vulnerable to legal attack. The Environmental Protection Agency (EPA) might be required to demonstrate that the O_3 standard is set at a level required to prevent human health problems. It is not clear that this standard could be defended on that basis.

At the same time that the basis for the ozone standard was changed, the one-hour standard level was raised from 80 to 120 ppb. This is probably a valid change because large concentrations of O_3 (probably up to 60 ppb) occur naturally over large areas of the country under certain climatic conditions.

To give a daily indication of air quality most communities use a value of "Pollution Standard Index" (PSI), which is usually given by local radio and TV stations along with weather reports. To simplify things, only a single value of PSI is given—the one based on the pollutant with the highest concentration *relative to its standard*. The PSI scale, also called the "Air Quality Index" (AQI), is defined so that a pollutant has a PSI value of 100 when the concentration is equal to the standard. A classification scheme that describes the quality of air (as shown in the table in the student module page 61) in terms of the general health effects of the pollutants is used in conjunction with PSI reports. When it is anticipated that the PSI will exceed 100, people with respiratory ailments may be advised to stay indoors. When a very high PSI reading is found, local authorities may require major industries in the area to shut down temporarily.

E-27 "HELLO," SULFUR DIOXIDE

E-28 CONTROLLING SO_2—THEN WHAT?

Our understanding of the role of SO_2 in air pollution continues to change. As discussed in the student module, SO_2 was originally thought to be the major culprit in air pollution. Successful measures were taken to reduce the exposure of large population groups to SO_2, but there was little change in the total release of SO_2. While these measures were being carried out, the EPA's epidemiological study of the effects of air pollution on people—the Community Health and Environmental Surveillance System (CHESS)—indicated *that sulfates, rather than SO_2 itself, were the* cause of major health problems associated with air pollution. During the middle 1970s, the emphasis in air-pollution prevention shifted to the control of sulfates, whose levels had not been reduced by the measures that reduced SO_2 concentrations. As air masses containing SO_2 travel over long distances, sulfates are formed slowly by atmospheric reactions that are not well understood despite 20 years of intensive study. Since 1976, the Electric Power Research Institute has supported studies that examine the release of SO_2 and the formation of sulfates over the entire northeast quadrant of the United States, but the results of these studies have not yet been fully interpreted.

In the meantime, the design and results of the CHESS studies have been severely criticized and the results are largely discounted by most authorities on air pollution. This does *not* mean that sulfates are not harmful; at some unknown, high concentration they undoubtedly cause harmful effects. It simply means that the CHESS studies did not prove that sulfates, at levels encountered in the atmosphere, are harmful to human beings.

In any case, since the CHESS studies are discounted, air pollution concerns have shifted toward visibility degradation and acid precipitation. We note, however, that SO_2 and sulfates are intimately involved in these problems. As we discuss in section *E*-33, visibility degradation is caused mainly by particles of a radius of less than 1 μm. In most areas, about half of the mass of these fine particles consists of sulfates, especially of $(NH_4)_2SO_4$. The acids of acid precipitation are mainly a mixture of sulfuric, nitric, and hydrochloric acids, with the first two usually predominating. Thus, once we understand these problems better, we will probably find it necessary to control SO_2 production or to control production of some other chemical species involved in the conversion of SO_2 to sulfates and sulfuric acid. This action will be necessary even if sulfates do not cause any proven human health problems. It is probable that a decrease in the release of SO_2

from fossil-fuel power plants and sulfide ore smelters, its major sources, will be mandated because of the conversion of SO_2 to chemical species involved in visibility degradation and acid precipitation.

Note that the SO_2 situation is one of many in which environmental and energy problems are in conflict. One of the proposed solutions to the current energy crisis is the increased use of coal. But unless the SO_2 emissions that result from burning coal are controlled—by SO_2 scrubbers in the emissions stacks of major sources, for example—the increased use of coal will exacerbate environmental problems caused by SO_2.

MINIEXPERIMENT
E-29 SULFURIC ACID IN ACTION

The purpose of this miniexperiment is to observe the effects of sulfuric acid on different materials.

Concept

- H_2SO_4 is a very strong and reactive acid.

Objective

- Predict the effect of H_2SO_4 on certain materials. Learn to handle H_2SO_4 with respect.

Estimated Time 20 minutes

Student Grouping Pairs

Materials

3 M H_2SO_4 in dropping bottle
pieces of concrete, glass, marble chips, fabrics, metal, paper, and so forth
watch glasses *or* petri dishes

Laboratory Safety Caution students about safe methods of handling sulfuric acid. Protective glasses and aprons are *mandatory* in working with H_2SO_4, as they should be for all laboratory activities.

Prelab Discussion Conduct a brief safety review, and discuss the proper method for disposal of materials.

Postlab Discussion Conduct a discussion based upon results obtained by students. Illustrate your discussion with equations wherever appropriate. For example, the formation of CO_2 from the reaction of H_2SO_4 with marble chips may be stated as

$$CaCO_3(s) + H_2SO_4(aq) \longrightarrow CaSO_4(aq) + CO_2(g) + H_2O(l)$$

E-30 IT ISN'T RAINING RAIN

It is useful at the outset of this discussion to note that pure water, when in equilibrium with the atmosphere, has a pH of 5.6, *not* 7 because of the formation of carbonic acid. This value is the pH of water in equilibrium with a partial pressure of 3.4×10^{-4} atm of CO_2.

Although it appears that precipitation has become more acidic over the past twenty years or so in the United States, there are very few long-term data on the pH of rainfall at a given location, so this trend is not very well established. Many monitoring studies and other kinds of research on this subject are now in progress under the Multistate Atmospheric Power Production Pollution Study (MAP^3S) program, which was initiated by the United States Department of Energy and then shifted to the EPA. A network of stations operated by the Agriculture Experiment Stations in many states are also involved in this research.

Our understanding of the mechanism by which acid rain is formed is very poor. Today many experts believe that the main reactions occur in clouds. Air containing SO_2 and nitric oxide (NO) passes through clouds, and portions of those gases dissolve in the cloud water droplets and undergo reactions that form acids. If the cloud forms precipitation, the acid is brought to ground level. However, most people are surprised to learn that only about one cloud in ten thousand forms precipitation; most clouds evaporate, leaving their dissolved materials behind in the form of fine particles. Cloud-water reactions may be a major mechanism for conversion of SO_2 to sulfates. Although these ideas are mostly unproved theories, it seems unlikely that raindrops or snow crystals falling through air containing SO_2 and nitrogen oxides (NO_x) would provide an opportunity for significant formation of acid during their brief journeys.

Unless acidic rainfall is neutralized by reactions with soil or rocks, lakes receiving the water may become quite acidic. A marked decrease in the

fish population has been detected in the lakes of Scandinavia and of the northeastern United States where water pH has decreased.

EXPERIMENT
E-31 pH OF RAINFALL

The purpose of this experiment is to measure the pH of rainwater in the area.

Concept

- The pH of rainwater varies significantly from the expected value.

Objectives

- Measure the pH of rainwater.
- Interpret pH values of rainwater based upon local air-quality conditions.

Estimated Time 15 minutes

Student Grouping Pairs

Materials

pH meter(s) *or* set(s) of pH indicator papers (for example, pHydrion papers covering the range of pH from about 3 to 7)
15 beakers

Prelab Discussion Mention that "normal" rainwater will have a pH lower than 7 because of the presence of CO_2 in the air. If you are using pH paper encourage students to take the measurements in the field, as the pH of a sample can easily change by 0.5 if the sample is left standing for very long.

Postlab Discussion The discussion will be based upon the range of results obtained for the particular location.

Answers to Questions

Answers will vary according to local conditions.

Miniactivity Note that the previous experiment provides unlimited possibilities for real research on the extent of acid precipitation in your area. To obtain data from a wider area, you could perhaps have students coordinate your school's study with those of other schools spread throughout your state. The northeast quadrant of the United States is under intense study, as noted in section *E-30*, but other areas have received very little study. Thus, if your students do a careful job, the results may be publishable in journals such as the *Journal of Chemical Education* or *SciQuest*. Or, you may obtain coverage in the popular press in your area. For best results, try to obtain a good pH meter, standardize it frequently with two buffer solutions of different pH values, and measure sample pH as soon as possible after sample collection.

E-32 CAN ANYTHING BE DONE?

As we noted in the student module, SO_2 can be scrubbed from the gases in emissions stacks of coal-burning plants, but the process reduces the overall efficiency of the heat-to-electricity conversion, and it will increase the cost of electric energy on the order of 15 percent. The process also yields much solid waste: the scrubber sludge contains $CaSO_3$ and $CaSO_4$, trace elements, and fly ash (small particles of mineral matter released when the coal is burned). Each ton of coal burned produces about one-third of a ton of sludge. The sludge must be disposed of carefully in landfills or sludge ponds to prevent leakage into the groundwater system.

Techniques by which stack-gas SO_2 can be converted into sulfuric acid, a useful product and another example of a resource-out-of-place, have been developed. This process is economically feasible and is now used in emissions stacks with very high SO_2 concentrations, mainly in those of sulfide ore smelters. But the concentration of SO_2 is lower in power plant stacks, and the sulfuric acid produced would be too low in concentration to be very useful in the chemical industry. The ideal process would convert SO_2 to pure sulfur, the most condensed and, thus, the cheapest chemical to ship to plants that convert sulfur into H_2SO_4. The United States Bureau of Mines recently developed a process in which SO_2 is reduced to sulfur by the action of citric acid; this is clearly a step in the right direction.

Miniactivity Here's an interesting calculation for your students. The table on page 59 of the student module indicates that about 27 million metric tons of SO_2 are

released per year as a result of human activities in the United States. How much sulfuric acid could be made from this amount of SO_2?

$$27 \times 10^6 \times \frac{98}{64} = 41 \times 10^6 \text{ metric tons}$$

The annual United States production of sulfuric acid (the product produced in highest volume by the chemical industry) is about 30 million metric tons. It would obviously not be economically feasible to equip all smaller SO_2 emissions stacks with conversion plants, but even so, efficient utilization of this resource-out-of-place could supply a major fraction of the country's needs.

E-33 ON A CLEAR DAY

You might suppose that the particles in dense, black smoke from an emission stack are quite large. But most of the visible particles have radii in the range of 0.1 to 1 μm, whereas the largest suspended particles have radii in the range of 20 μm or greater. Particles of radii of 10 μm or less have such small settling rates that they stay suspended until trapped on a surface (for example, plant leaves) or until they are brought down by rain or snow. The average residence times of such particles in the lower atmosphere (the "troposphere") are about 6 to 10 days.

The 0.1- to 1.0-μm particles that produce haze are also in the particle-size range that most effectively penetrates deep into lung passages (what you see is what you breathe). Unfortunately for smokers, a major fraction of cigarette smoke particles are of this size range. You can, of course, see light scattering from cigarette smoke quite clearly when it passes into a beam of sunlight or into a projector beam.

As in the case of many other air pollutants (although not with certain chemical elements such as lead), natural processes probably release far more particles than do human activities. But the problem of anthropogenic particles is that they are often released in high concentrations in major population centers.

The release of particles from many factories and power plants can be greatly reduced by passing their stack gases through filtering devices or, more frequently, through electrostatic precipitators. In the latter, the gas stream passes between a series of plates of alternating high-electrical potentials (many thousands of volts). Particles acquire charges and are attracted to the plates and collected before they can be released.

Modern electrostatic precipitators can remove 99+ percent of the mass of suspended particles in effluent gas streams. Precipitator efficiencies are, unfortunately, usually highest for very large particles and lowest for particles in the 0.1- to 1-μm size range—the particles that cause most of the light scattering and health effects. Particles may also be removed by passing the stack gases through fabric filters.

As discussed in section *E-43*, a major particulate-matter problem now under consideration is the emission of particles from diesel-powered automobiles. As long as only a few automobiles have diesel engines, this problem will not be too serious. But at least one major automobile manufacturer is counting heavily upon using diesel engines in new automobiles to meet Federal fuel economy standards (fleet average of 27.5 miles per gallon). If everyone were to switch to present-day diesel cars, the particulate matter released by their engines would considerably reduce visibility in urban areas.

EXPERIMENT
E-34 LIGHT SCATTERING

In this experiment students will observe light scattering by particles of different sizes.

Concept

- Haze is caused by the scattering of light by particles suspended in the air.

Objective

- Demonstrate and explain the Tyndall effect.

Estimated Time 20 minutes

Student Grouping Class demonstration

Materials

1 aquarium *or* flat-sided jar
1 slide projector
1 projection screen *or* light-colored wall
100 cm^3 0.1 M $Na_2S_2O_3 \cdot 5H_2O$
100 cm^3 0.1 M HCl

Advance Preparation Set up the aquarium, half-filled with water, and the projector and screen.

Prelab Discussion You may wish to define the term *colloid* and give some examples of relative sizes of particles. It may also help to conduct a short discussion on the nature of light, its wavelengths and frequencies. You can show the different components of the visible light spectrum with a prism. Show the effect of removing some wavelengths of light by using one or more filters.

Laboratory Tips You can control the rate of formation and growth of the sulfur particles by varying the amount of water in the aquarium and the concentrations of the thiosulfate and hydrochloric acid. It is suggested that you "play" with this demonstration before doing it in class. This will enable you to set the conditions to run the demonstration in your class period. It is important that the reaction occurs slowly enough so students can see the several colors of light produced. Stir the particles occasionally throughout the experiment.

Postlab Discussion Remind the students that this demonstration is just a model for the light scattering observed when light travels through the atmosphere under different conditions. The colloidal sulfur that precipitates in the reaction in the aquarium has nothing to do with SO_2 pollution.

The degree of light scattering observed is related to the wavelength of the incident light and to the size of particles in its path (cross section). As the size and number of colloidal particles increase, longer wavelengths of light will be scattered. This phenomenon explains the progression of colors both in the aquarium and on the screen.

This selective scattering helps us to understand the color of the sky and that of the Sun when it is overhead. The molecules present in the upper layers of the atmosphere scatter the short-wavelength component of the visible spectrum of light. As the Sun sets, the light rays must travel through more of the lower layers of the atmosphere; the light waves pass through a longer pathway of particles and molecules than they do when they come straight down from the overhead position. Thus, the longer wavelength components are scattered, giving rise to the reddish sunset.

Answers to Questions

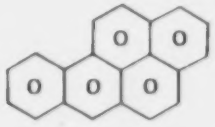
1. The short wavelengths of light (bluish) are scattered first by the very fine particles initially formed.
2. The projected light initially contains all visible colors and therefore appears white on a white background. As soon as particles start to scatter blue out of the beam, transmitted light is white minus colors in the blue region—yellow.
3. As particles grow, longer wavelengths are scattered and the spectrum shifts away from blue, becoming more "white." Transmitted light loses intensity and appears deeper orange-red.
4. The last light transmitted appears reddish.
5. When the Sun is overhead, the entire sky is illuminated by sideways scattering of incoming light. Since scattering is by molecules and fine particles, the shortest wavelengths are scattered, producing a blue sky. When the Sun is at a low angle, the sky in that direction is illuminated by the transmitted light that is the complement of the blue—red.

E-35 THE PARTICLES WE BREATHE

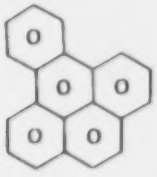
Until the present, the concentration of total suspended particulate material (TSP) has been monitored by pumping air through "8- × 10-in." high volume (Hi-Vol), glass-fiber filters with pumps similar to those used in vacuum cleaners. The mass of the filters is determined before and after air collection to determine the net mass. The TSP standards are based upon this type of measurement, which does not classify particles according to size. TSP levels were reduced considerably in most cities during the 1970s. Most of the reduction of mass took place among large particles, however; for example, particles of windblown dust from construction sites were reduced by wetting down the dust with water.

As we go to press, a group of scientific advisors to the EPA is formulating recommendations for new TSP standards. It is almost certain that a standard based upon the size of particles will be adopted. At a minimum, particles of a diameter less than 15 μm (radius less than 7.5 μm) will be specified. Some scientists are pushing for regulation of TSP in two size ranges, probably the 2-15-μm size and the less-than-2-μm size.

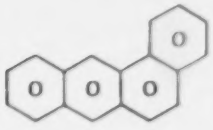
The effects of particles on human health also depend upon their compositions. As more is learned about the effects of certain elements and compounds on the human body, we may see the adoption of standards for additional elements and compounds; such a standard now exists for lead. At present there is growing concern about the possible effects of organic materials, especially compounds that are carcinogenic, upon airborne particles. A major class of organic compounds that contains many carcinogens are the polynuclear aromatic hydrocarbons. Some examples are shown here.



benzo[a] pyrene (highly carcinogenic)



benzo[e] pyrene (not carcinogenic)



benzo[a] anthracene (mildly carcinogenic)

About twenty of the polynuclear aromatic hydrocarbons are formed in the combustion of carbon-containing fuels any time the carbonaceous material oxidizes incompletely. Automobile and diesel exhaust, oil furnaces, coke ovens in steel mills, cigarettes, and other combustion sources produce these compounds. Another source is charcoal grills, which operate under very poor oxidizing conditions.

ANSWER TO PROBLEM
(Student module page 71)

Encourage students to use as much imagination as possible in arriving at solutions to a problem in your area. This "problem" may easily be expanded by having students conduct research—looking up local ordinances, discusssing the problem and its solutions with local authorities, plant managers, and so forth. Have students report their findings to the class.

E-36 AUTOMOBILE EXHAUSTION

Before discussing problems created by the automobile, it would be useful to describe the basic features of the internal-combustion engine: how it works, what the carburetor setting does, and so forth. Most students know little about automobile mechanics but find the subject interesting.

Miniactivity Here is an opportunity to have students do stoichiometric calculations on a "real world" problem. Have them compute the mass ratio of O_2/C_8H_{18} for complete combustion and the mass ratio of air/$C_8H_{18}(g)$, that is, the carburetor setting.

Answers: $O_2/C_8H_{18} = 3.8$
air/$C_8H_{18} = 16.3$

Remember that O_2 makes up only about 21 percent of air.

Both carbon monoxide (CO) and hydrocarbon emissions (HC) from automobiles can be decreased by adjusting the carburetor to a "lean" mixture, that is, to an air/fuel ratio of about 14/1 or higher. Such a mixture burns at a higher temperature than a rich mixture, however, causing formation of more NO by the following endothermic reaction.

$$N_2(g) + O_2(g) \longrightarrow 2\ NO(g)$$

You may find your students interested in learning more details about *why* the carbon monoxide generated by automobiles is toxic to people. The following background will help you to organize your discussion.

The hemoglobin (Hb) in red blood cells acts as a conveyor belt between the lungs and the cells throughout the body. Oxygen passes through thin membranes of the lung and becomes attached to Hb molecules. The bloodstream carries oxygenated Hb to the cells where O_2 is needed (for oxidation of glucose, for example), and the loosely combined O_2 detaches. Some of the CO_2 from the cells (the product of oxidation) is attached to Hb—the remainder travels as HCO_3^- dissolved in blood—and is carried back to the lungs, where CO_2 detaches and more O_2 climbs aboard.

The problem with CO is that it has a much stronger affinity, by a factor of about 200, for Hb than O_2 does. Even though the concentration of CO in the air may be only 100 ppm or less, a small percentage of the Hb will be tied up by CO, and the CO does not become detached easily. Even after a CO poison victim has been moved to fresh air, it takes several hours for the CO level to decrease to normal.

The effects of CO result from O_2 deprivation. The first effects show up in the brain. The symptoms produced at various fractions of Hb converted to the HbCO form are shown in the table. The 60-percent level, which causes death, is produced by exposure to 600 ppm CO for about eight hours or by shorter exposures to higher concentrations. According to older literature, minor symptoms, such as headache, occur at the 10-percent HbCO level, which is produced by exposure to 100 ppm CO for three hours or 600 ppm CO for about 30 minutes. More recent studies have shown slightly decreased ability to do mathematical problems at HbCO levels as low as 2 percent!

Symptom	*% HbCO in blood*
Headache, reduced mental sharpness	10
Throbbing headache	20
Vomit, collapse	30
Coma	40
Death	60

The problems of cigarette smoking arise in part from incomplete combustion of the organic compounds of tobacco. If combustion were complete, the resulting CO_2 and H_2O vapor would be harmless, and the cigarette would be "tasteless." Combustion is unfortunately not complete, so the smoker inhales both CO and unburned hydrocarbons. During the day, a heavy cigarette smoker maintains a HbCO level of about 5 percent or more; this is a good reason for not smoking while studying and working problems! High HbCO levels are probably some of the major causes of the increased incidence of cardiovascular diseases among cigarette smokers. You might think that drivers of cars in heavy traffic, especially if they are smoking, would have unusually high accident rates because of decreased mental alertness. A study by H. K. Ury, N. M. Perkins, and J. R. Goldsmith (*Archives of Environmental Health*, Nov. 1972) indicated a direct correlation between accident frequencies and oxidant concentrations (mainly O_3), but no link with CO levels was found. Students should be made aware of the fact that it is extremely difficult to prove direct causal relationships between levels of specific pollutants and incidences of diseases. For example, suppose statistics show that urban residents have unusually high rates of respiratory illness. Is this because of high levels of SO_2, particles, CO, O_3, or hydrocarbons in the urban air? Or could it be caused by the fact that people who are sick might move to a city to obtain good medical treatment? Many factors must be considered.

Demonstration Teachers who have experience with biology experiments may wish to perform the following demonstration to show the defenses of the lungs. Dissect a frog, opening up a lung to expose the cilia-covered surfaces. Then subject the lung surface to irritants such as cigarette smoke or chemical fumes. SO_2 or HCl fumes may be used as stimulants. In response to the irritants, the cilia will wave back and forth as they would in an intact, living lung attempting to remove the irritants.

E-37 PHOTOCHEMICAL SMOG

The atmospheric reactions that produce smog are very complicated and not fully understood. It is known that nitrogen oxides, hydrocarbons, carbon monoxide, and sunlight are essential ingredients. Just as in the case of SO_2, natural sources of

hydrocarbons provide much larger quantities of these substances than do human activities. Biological decomposition produces great quantities of methane, which, in this context, is called "swamp gas." Pine forests release vast quantities of terpenes that condense to form particles that produce a bluish haze, such as the "smoke" in the Great Smoky Mountains. However, today the haze is dominated by sulfate particles, just as it is in most other areas of the eastern United States.

Although in some areas most of the nitrogen oxides (NO_x) are produced by automobiles, it should be noted that all high-temperature combustion processes that are carried out in the air form NO_x. Note in the table on page 57 of the student module that transportation accounts for only about half of the total NO_x produced by human activities in the United States. Skeptics wonder whether the strong efforts to decrease NO_x emissions from autos will do much good unless other sources are controlled.

Los Angeles used to be thought of as the only large city with a major photochemical smog problem. Indeed, smog has been a very serious problem in Los Angeles because conditions are ideal for it: (1) high traffic density; (2) abundant sunlight, which initiates photochemical reactions; (3) warm temperatures, which speed up most chemical reactions; (4) frequent temperature inversions, which trap pollutants at low altitudes; and (5) mountains on three sides, which form a basin that slows outward horizontal movement of air. However, as better monitoring was extended to all cities in the United States, it was found that most cities had frequent violations of the old standard for photochemical oxidants during warm, sunny periods. In Washington, D.C., for example, most of the days on which the air quality index reached unacceptably high levels occurred in the summer; these unacceptable readings were caused by high photochemical-oxidant levels.

As is true in sulfate formation, the formation of ozone and other photochemical oxidants is a process that takes many hours. If a wind is blowing, therefore, smog may form 100 km or more downwind from the source of the primary pollutants. Urban plumes of pollutants from St. Louis and New York City, for example, have been found to produce high levels of photochemical oxidants in eastern Illinois and in Boston, respectively, after many hours of transport by the wind. Thus, except in rather special situations such as in the Los Angeles Basin, smog problems can only be controlled by a regional approach; local control of emissions cannot solve the local problem.

To see if students are alert, you might pose this hypothetical problem: Suppose you are the local air quality manager. Citizens complain to you because the local ozone levels frequently exceed the air quality standard. How could you relocate the ozone-measuring stations to give lower values? *Answer:* Put the stations next to the busiest intersections in town. Because of the very rapid reaction,

$$NO + O_3 \longrightarrow NO_2 + O_2$$

the high levels of NO from auto exhaust will greatly reduce the O_3 concentration. Of course, you will not have done anything to solve the air pollution problem; the problem will just appear less serious to the uninformed.

In the following sections, we discuss some of the measures that must be taken to improve air quality. The irony of this situation is that NO, which suppresses O_3 accumulation over short periods of time, reacts with hydrocarbons and other species to form O_3 during longer time intervals.

EXPERIMENT
E-38 NO_2 WAYS ABOUT IT

In this experiment students will determine the amount of NO_2 in an air sample taken from the environment.

Concepts

- NO_2 can be collected by an absorbing agent.
- The NO_2 sample collected reacts with other chemicals to form a colored complex.
- The intensity of the color produced in this reaction depends upon the amount of NO_2 present.
- The intensity of color can be measured either with a spectrophotometer (if available) or by visual comparison with standards.

Objectives

- Calibrate a pump.
- Collect a sample of NO_2.

- Set up a standard curve with the spectrophotometer (if available).
- Use NO_2 in the sample to form a colored complex, find the absorbance of the colored complex on the spectrophotometer, and use the standard curve to determine the milligrams of NO_2 present in the sample.
- Calculate the parts per million of NO_2 present in the sample if given the information in the steps above.

Estimated Time Prelab (pump calibration, preparation of sampling device): 1 hour; samples taken as homework
Lab: 1 hour; standard curve graphed as homework
Postlab: 15 minutes

Student Grouping Pairs

Materials

First Day of Lab

15 bicycle pumps or similar devices
15 sample-collecting devices
750 cm^3 absorbing reagent

Second Day of Lab

15 25-cm^3 graduated cylinders
spectrophotometer and cuvettes
15 150-cm^3 beakers
15 10-cm^3 graduated cylinders
5 50-cm^3 graduated cylinders
5 1-cm^3 pipettes with bulbs
2 liters absorbing reagent
50 cm^3 of hydrogen peroxide solution
1 liter of sulfanilamide solution
100 cm^3 of N-NED reagent
1 liter of standard $NaNO_2$ reagent

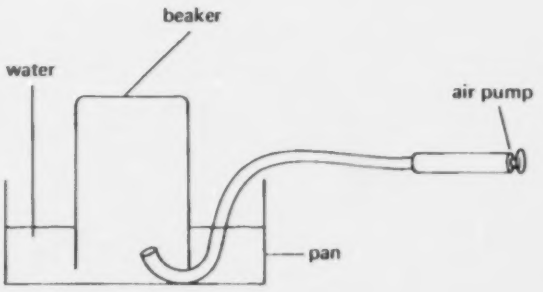
Advance Preparation

First Day of Lab

Air-collecting equipment One of the most difficult problems in air pollution experiments is that of obtaining the sample. The first piece of equipment necessary for air pollution sampling is a bicycle pump or a similar device.

Calibrating the pump Check the volume of air passing through the pump with each stroke. Use a 250-cm^3 beaker or graduated cylinder for this calibration.

1. First fill the beaker or cylinder with water and invert it into another pan of water. Use a glass plate to invert the beaker.
2. Take a piece of tubing and connect the air pump to the inverted beaker.
3. Push in the handle of the pump to discharge the air in the pump. This air will replace water in the beaker. Mark the point on the beaker at the air line.



4. Invert the beaker, and fill it to the mark with water.
5. Measure the volume of water to the mark in a graduated cylinder. This is the volume of air in one stroke of the pump.
6. Repeat this calibration two more times and take the average value of the volume per stroke. The next step is to build a sample-collecting device.

Building a Sample-Collecting Device A 50-cm^3 Erlenmeyer flask or a 50-cm^3 test tube will be sufficient for sampling.

1. Connect an eye dropper to an intake line. A diagram of the equipment is shown in the student module. Be sure that the eye dropper (bubbler) is close enough to the bottom of the flask to be covered by the absorbing reagent, but not so close as to stop air flow.
2. Now the equipment is ready for the reagent necessary for sample collection. It is important that the reagents *not* be placed in the sampler until you are ready to sample.

Procedure for NO_2 collection

1. Place 25 cm^3 of NO_2 absorbing reagent into the sample collector. Seal with a stopper until you are in the field.
2. Once in the field you can begin pumping sample air through the sampling container with the bicycle pump. Don't pump more than 250 cm^3/min of air through the bubbler. Faster sample flow will not allow enough NO_2 in the sample to reach the absorbing reagent at the outside of the air bubble.

3. Continue to pump until at least 10 000 cm^3 of sample air have been pumped through the sampling container. To determine how many pump strokes you will need to obtain this volume, divide 10 000 cm^3 by the capacity of your pump in cm^3.

Second Day of Lab

Prepare solutions as follows.

Absorbing reagent Put 4.0 grams of NaOH into a 1-liter volumetric flask and dilute to 1 liter.

Sulfanilamide reagent

1. Add approximately 300 cm^3 of distilled water to a 1-liter volumetric flask.
2. Add 20.0 g of sulfanilamide to the water.
3. Slowly add 50 cm^3 of H_3PO_4 to the solution.
4. Dilute the solution to 1 liter with distilled water.

N-NED reagent Put 0.20 grams of *N*-(1-naphthyl)-ethylene diamine dihydrogen chloride into a 200-cm^3 volumetric flask. Dilute the solution to a 200-cm^3 volume with distilled water.

Hydrogen peroxide Pipet 0.2 cm^3 of 30 percent H_2O_2 into a 250-cm^3 volumetric flask. Dilute the solution to a 250-cm^3 volume with distilled water.

Standard $NaNO_2$ reagent

1. Put 0.6 g of $NaNO_2$ into a 1-liter volumetric flask. Dilute to 1 liter with distilled water. The standard now contains 0.6 g of $NaNO_2$/liter.
2. Take 100 cm^3 of the solution and dilute to 1 liter. The sample now contains 0.06 g $NaNO_2$/liter.
3. Take 300 cm^3 of the 0.06 g $NaNO_2$/liter solution and dilute to 1 liter. The standard now contains 0.018 g of $NaNO_2$/liter or 18 mg $NaNO_2$/liter, which is equivalent to 12 mg NO_2/liter.

Prelab Discussion Discuss the reason for pump calibration or why it is important to determine how much air each cycle of the pump contains. (A known volume of air must be obtained for the sample.) Explain to students why the water displacement method for taking a gas sample is used. (If a gas is displaced, you can't see it.) Explain why the glass tube must have a small opening. (A small tube makes smaller bubbles, and more air at the surface of the bubbles comes in contact with the absorbing solution.) Discuss the fact that the NO_2 absorbing reagent traps the NO_2 in the air. After reagents are added to the NO_2, reagent molecules react with NO_2 molecules to form a colored complex. Then the more NO_2 molecules present, the darker the color of the solution. The intensity of the solution's color can be measured with a spectrophotometer or by visual comparison to standards made with known concentrations of NO_2. Such standards provide a color range to which the samples can be compared.

Laboratory Safety Review with your students safety precautions related to the handling and disposal of chemical solutions. See additional precautions in the *Laboratory Tips* section.

Laboratory Tips Suggest that students collect samples from areas where there are likely to be very high concentrations of NO_2, for example, near busy intersections, in parking garages, and so on. As is the case for most air pollutants, NO_2 is so dilute that it is very difficult to collect enough of it to obtain a good reading with conventional equipment. Be sure students record the location at which each sample was taken, as well as the absorbence or standard comparison, so they can compare location and NO_2 concentration later.

If you live in an area with relatively little NO_2, you can insure high concentrations of NO_2 in a few samples by generating some NO_2 in the lab. *Under a hood*, pour some concentrated HNO_3 over copper turnings. The brown gas given off is NO_2. Have students take a sample near the hood. *Be careful! NO_2 is toxic.* Students like to take samples of air behind the exhaust of running cars. Advise them not to do this, and definitely not in a closed garage.

If you plan to use visual comparison of standards rather than a spectrophotometer, and students have difficulty distinguishing among the standards given in the student module, you should have the students make up the standards using these volumes of standard $NaNO_2$ solution: 0, 2.0, 4.0, 6.0, and 8.0 cm^3. Your concentrations will be, respectively, 0, 0.024, 0.048, 0.072, and 0.096 mg of NO_2.

If a spectrophotometer is available, set the wavelength at 540 nm.

Range of Results In very clean areas, students may not be able to detect NO_2. This result does not indicate a zero concentration but simply a concentration below the detection limit for this method. In heavily impacted areas, the NO_2 concentration may exceed the standard.

Answers to Questions The answers will depend on the sampling locations selected by students.

E-39 LEAD AS AN AIR POLLUTANT

Dichloroethylene and dibromoethylene are added to gasoline along with TEL (or tetramethyl lead, TML) to provide chlorine and bromine for reaction with lead to make volatile lead halides that leave the cylinder in the exhaust. You wouldn't want the lead to be deposited in the engine, and especially not on the spark plugs. About half of the lead is emitted immediately in the hot exhaust in the form of very fine particles with diameters of less than 1μm. Particles of these small sizes are of greatest concern from the point of view of health because they penetrate deep into the lungs.

The concentration of lead in the blood of most persons falls in the range of 5 to 20 μg Pb/100 cm^3. Concentrations above 50 μg Pb/100 cm^3 generally indicate some unusual exposure to lead. Symptoms of lead poisoning generally start to appear at blood lead concentrations between 50 and 80 μg Pb/100 cm^3; there is a very small margin of safety against lead poisoning. Recent evidence suggests that many children without overt symptoms of lead poisoning are still affected by lead in more subtle but serious ways. At levels above 40 μg Pb/100 cm^3, studies indicate that children perform less well in school and have more behavioral problems than do their counterparts who have lower Pb levels.

The average resident of an industrial nation takes in about 300 μg Pb/day in food and beverages and 30 to 40 μg Pb/day from the air. However, only about 10 percent of the lead in food and beverages is retained by the body, whereas about half of that breathed in is retained. Thus, about half the lead in the body of an urban resident comes from the air.

Since only very small amounts of Pb and other toxic metals are needed to cause observable symptoms, these metals must affect biochemical species in the body that are present in very small amounts. For this reason, and on the basis of some direct observations, it is thought that most toxic metals achieve their effects by interference with the actions of certain types of *enzymes*, biochemical catalysts present in extremely minute amounts in the body. Lead, for example, is known to block the action of the enzyme delta-aminolevulinic dehydrase, which affects porphyrin metabolism and decreases hemoglobin synthesis.

Because of the very small difference between typical lead concentrations in the body and the concentrations at which poisoning symptoms appear, an unusual exposure to lead can cause serious problems. Such exposures may come from many sources, such as living next to a heavily traveled highway, working as an attendant in a highway tunnel, ingesting leaded paint or putty, ingesting street dust, or ingesting food or beverages cooked or stored in improperly glazed pottery.

You can check for leachable lead from pottery by allowing a 4-percent acetic-acid solution to stand overnight in the suspected container and then performing the lead analysis of section *E-41* on the resulting solution.

It should be noted that whereas many problems discussed in this module are potential ("what might happen"), the lead problem is very real—many children have died or have become quite ill from lead poisoning. A much greater number of children may perform poorly in school because of the subtle effects of lead. Lead exposure caused by automobile emissions is fortunately being reduced because of the use of catalytic converters.

EXPERIMENT
E-40 LEAD ASTRAY

The purpose of this experiment is to analyze soil samples collected near highways for the presence of lead.

Concept

- Lead salts are emitted into the atmosphere in automobile exhaust from the combustion of leaded gasoline.

Objectives

- Collect soil samples for lead analysis.
- Measure the amount of lead in a sample by titration with EDTA.

Estimated Time One period. Students can collect the sample before coming to class (see Advance Preparation).

Student Grouping Pairs

Materials

15 150-cm^3 beakers
15 250-cm^3 Erlenmeyer flasks
30 glass stirring rods
15 burets and buret clamps
1000 cm^3 0.1 M HNO_3
methyl orange indicator
1000 cm^3 0.1 M NaOH
2 g tartaric acid
200 cm^3 ammoniacal buffer
100 cm^3 Eriochrome Black T Indicator Solution
1000 cm^3 0.001 M EDTA (ethylenediaminetetraacetic acid)

Advance Preparation Try to collect fine soil. Avoid large stones or any other objects.
Prepare solutions as follows.

0.1 M HNO_3
Add 6.5 cm^3 concentrated HNO_3 (15 M) per 1000 cm^3 solution.
Dilute NaOH (0.1 M)
Add 4.0 g NaOH per 1000 cm^3 solution.
Ammoniacal buffer (pH = 10)
Add 120 cm^3 concentrated NH_4OH to 14 g NH_4Cl. Dilute with water to 200 cm^3.
Eriochrome Black T Indicator
Add 4 cm^3 ammoniacal buffer to 0.2 g Eriochrome Black T. Dilute with water to 100 cm^3.
0.0010 M EDTA
Dissolve 0.372 g reagent grade disodium ethylene dinitrilotetraacetate dihydrate in water and dilute to 1000 cm^3.

Prelab Discussion Review section *E-55*.

Laboratory Tips Put the ammoniacal buffer in a dispensing buret because its odor is rather offensive.

Answers to Questions Concentrations of lead up to the 1 to 2 percent range may be found in soil immediately adjacent to highways or near the walls of houses that have been painted at some time with lead-based paint. In relatively clean areas, the lead concentration should be no higher than about 200 ppm.

EXPERIMENT
E-41 LEAD IN YOUR HOME?*

In this experiment students analyze paint or putty for the presence of lead.

Concept

- Toxic substances, such as lead, can sometimes be found in common materials, for example, paint or putty.

Objective

- Detect lead in a sample of paint chips or putty.

Estimated Time 45 minutes

Student Grouping Pairs

Materials

15 test tubes
100 cm^3 concentrated HNO_3
15 150-cm^3 beakers
15 ring stands and rings
15 wire gauze
15 Bunsen burners
50 cm^3 1 percent sodium sulfite solution, Na_2SO_3 (0.5 g/50 cm^3)
100 cm^3 20 percent potassium iodide solution, KI (20.0 g/100 cm^3 solution)

Advance Preparation Obtain two centrifuges (optional). Have your students collect pieces of paint chips and putty.

Prelab Discussion Several laws have restricted the sale of leaded paints. Therefore, students should try to collect paint chips from buildings which have not been painted since about 1965. White paints usually contain lead sulfates and oxides, and yellow paints contain lead chromate.

Laboratory Safety Review the general safety tips found in the appendix, particularly those related to the safe heating of materials with a Bunsen burner. Include a special precaution about the safe handling of nitric acid in your Prelab Discussion.

*Adapted from Kaplan, E. and Shaull, R. S. 1961. "Determination of lead in paint scrapings as an aid in the control of lead paint poisoning in young children." *American Journal Public Health* 51, No. 1:65.

Range of Results If the concentration of lead in the sample is greater than 1 percent, a yellow precipitate of PbI_2 will be formed. Traces of lead with concentrations below the 1-percent level are difficult to detect by these methods.

Postlab Discussion Relate the results of this experiment to the discussion of the effects of lead in section *E-39* of the student module. See section *E-39* in this teacher's guide for additional information.

It should be noted that a negative result in this experiment does not mean that the samples tested are lead free. Other, more sensitive, tests could show that trace quantities of Pb are present. You may need to explain the term "trace quantities" to the students.

Follow-Up If students obtain positive results for any *interior* samples, we suggest that you have additional samples brought in from the dwelling in question. If the positive results are confirmed, we suggest that parents be notified of the presence of lead, but without raising undue alarm. Encourage them to have local authorities come in and conduct professional tests for lead paint and, if found, to recommend procedures for removal.

E-42 UNCLEAN AT ANY SPEED?

Much development and testing are under way in the automobile industry to meet the more stringent federal emissions requirements of the 1980s. At this time, the final solutions to the automobile emissions problems are not clear; a single catalyst or a series of two catalysts may be used. If two are used, the first would be a reducing catalyst in which CO and other reduced species would reduce NO to N_2 or, possibly, all the way to NH_3. In order to provide the proper amount of reducing species, the engine might be run with a little richer fuel/air mixture than in pre-1980 cars. In the second catalyst, CO and HC would be oxidized to CO_2 and H_2O. If NH_3 were formed in the first catalyst, it would be oxidized back to N_2.

These problems are very complicated because automobiles must meet not only emissions standards but also increasingly stringent fuel economy standards; by 1985 the fleet average for gasoline utilization must be 27.5 miles per gallon. The emission control systems must also be highly reliable for the life of the car because most states will probably require annual emissions tests for automobiles. Some states already have these requirements. Those cars that fail the tests while under manufacturer's warranty will be fixed at the manufacturer's expense unless the owner has removed the pollution controls or otherwise ruined them, for example, by using leaded gasoline. The emissions controls must also operate properly under a wide range of conditions from cold start-up to hot engine.

In order to maintain proper control of engine parameters under a wide range of conditions, auto manufacturers will probably equip cars with "microprocessors." These are chips of silicon, similar to those in hand calculators, that will receive signals about engine conditions from various sensors in parts of the engine and will then send out signals to adjust various parameters of engine function (for example, the carburetor setting) to optimum levels. Some microprocessers are already used in automobiles sold in California, the state with the most stringent emissions standards. When the microprocessors come into extensive use, they may also be used to enhance fuel economy in various ways; for example, they may relay signals to shut off some of the engine's cylinders when it is running under a very low load.

The emissions controls, mainly on CO and HC, that were instituted during the 1960s have caused some improvements in air quality, at least in the Los Angeles Basin. The improvement is due, in part, to the reduced concentrations of reactants. Because of the reduction, the reactions that form photochemical oxidants are delayed, so the maximum oxidant concentrations tend to occur when the air has moved farther away from the urban area. The concentrations of photochemical oxidants at that distance don't usually reach levels as great as they previously did in the Basin because of dilution over a distance and lower initial reactant concentrations. Even so, smog is still a serious problem in Southern California, and it is not obvious that photochemical oxidant levels have been greatly reduced in other areas. The formation of smog requires many ingredients: NO_x, CO, HC, and sunlight. Any one of these can be made the limiting reagent. In many areas, NO_x is probably the limiting reagent, given sufficient sunlight, so reductions of HC and CO may not be effective. There are many sources of HC, including natural emissions from vegetation, but nearly

all the NO_x comes from high temperature combustion sources such as automobile engines and power plants. Although most of the attention on NO_x control is now focused on automobiles, "fuel combustion in stationary sources"—mainly power plants—produces more NO_x than transportation (see the table on page 57 of the student module).

E-43 CLEANER POWER FOR AUTOS

Most emissions controls on automobiles are involved in the cleanup of the exhaust. Another approach is to use engines of fundamentally different designs. During the middle 1970s, it appeared that the rotary ICE, the "Wankel" engine, might come into wide use; a type of car manufactured in Japan and equipped with this kind of engine enjoyed some popularity in the United States. These cars have good emissions characteristics, but their fuel economy was not good, and it now seems unlikely that such vehicles will come into wide use.

Another modification of the spark-ignition ICE is apparently more successful; this engine design is available now on another car made in Japan. This type of engine is called the "compound vortex controlled combustion" (CVCC) engine, commonly referred to as a "stratified-charge" engine. The cylinder is divided into two chambers that are supplied with air/fuel mixtures (the "charges") from separate carburetors. The charge in the main chamber is a very lean mixture, that is, it has such a high air/fuel ratio that its combustion produces very little CO and hydrocarbons. Such a lean mixture cannot be ignited by a spark plug. For this reason, the charge of the small chamber containing the spark plug is quite rich. Hot gases from combustion in that chamber ignite the main charge. At present, this appears to be the best ICE design from the standpoint of both emissions and fuel economy.

We should not forget the question of efficiency in the use of energy. It is clearly inefficient to transport one person weighing one hundred eighty "pounds" around town in a car weighing two "tons"! The *net propulsion efficiency* (NPE)—passenger miles per gallon of gasoline or equivalent energy—for one person in a car in urban areas is about 8. By contrast, consider the NPEs of the following:

Carrier	*Assumed Number of Passengers*	*NPE*
DC–8	78	20
Jumbo Jet 747	210	26
Auto-average use	2	35
Urban bus	12	40
Two-level commuter train	1200	120
Highway bus	22	135
Small bus	7	175

Source: R.A. Rice, "Systems Energy and Future Transportation," *Technology Review* 74(3):31 (1972).

Even with the partial loading assumed above, buses and trains are much more energy-conserving for transporting people than automobiles are. Not only do they use less fuel and thus emit fewer pollutants than the equivalent number of one or two passenger autos, but they can be fitted with more sophisticated emission-control devices or even use other power sources. Many major cities will probably have to use mass-transportation plans to reduce air-pollution levels to the desired limits in the future. Some kind of restrictions will probably be needed to reduce auto traffic in the cities—for example, entry charges, very restricted parking, low bus fares, and so forth. These ideas could provide much material for class discussions.

At least one major auto company is depending heavily upon the diesel engine to meet their fuel economy standards. Diesels can meet the CO and HC standards, but may have great difficulty with NO_x and particulate matter emissions. Filters for the exhaust system of such engines have been designed to reduce particulate emissions to the required levels, but these filters require cleaning about every 1600 km, or when they have collected about 1 kg of waste material.

Much effort is now going into the development of improved batteries for electric vehicles (EVs). Not only would electric cars save precious petroleum, but they would also reduce air pollution from autos in cities. (Depending upon the source of the electricity, there may be increased air pollution by the power plants, however.) At present, EVs are not fully competitive with conventional automobiles because the lead-acid storage batteries needed to give them an appreciable range between charges have a very large mass and because the cost of replacing batteries when they are no longer chargeable is quite high.

CHARACTERISTICS OF SEVERAL TYPES OF BATTERIES*

Type	Operating temp (°C)	Energy storage density (Wh/kg)	Estimated life (# recharges)	Estimated cost 1979 ($/kWh)
Lead-acid	Ambient	40	>1000	70
Nickel-iron	Ambient	55	>2000	100
Nickel-zinc	Ambient	75	> 500	100
Zinc-chlorine	30–50	90	>1000	75
Sodium-sulfur	300–350	90	>1000	75
Lithium-iron sulfide	400–450	100	>1000	80

*Source: "The Promise and Puzzle of Electric Vehicles." *EPRI Journal*, November, 1979, pp. 6–15.

In 1974, General Motors announced that they had made a "breakthrough" in the technology of zinc-nickel oxide batteries that will make EVs practical, probably by the mid-1980s. The energy costs for EVs even today would be smaller than those for gasoline-powered automobiles of similar size, but the initial cost and the cost of the replacement of batteries would make total EV costs higher. It is expected, however, that EVs will have much lower maintenance costs because of the simplicity and reliability of electric motors relative to ICEs.

Miniactivity Have students do various calculations to compare energy efficiencies of battery-powered and gasoline-powered cars. For example, have students calculate the equivalent energy storage density of gasoline using data from the unit on energy (sections *E-47* to *E-55*) and assuming gasoline has a density of about 0.9 g/cm^3. For a fair calculation, you must take into account the conversion efficiency of the device using the energy. The gasoline engine has an efficiency of 25 percent, while the electric engine has an efficiency on the order of 80 percent.

E-44 THE GREENHOUSE EFFECT

There is no doubt that human activities have contributed to the increase in the concentration of CO_2 in the atmosphere. Since 1958 very accurate records have been kept of CO_2 concentrations in the atmosphere. Within each year a cyclic fluctuation of CO_2 occurs, with the minimum falling in spring and summer and the maximum occurring in fall and winter. This suggests the great dependence of CO_2 concentration on photosynthetic activity.

The concentration of CO_2 is also an excellent example of both chemical equilibrium and the resilience of nature. Over the long haul, equilibrium between CO_2 in the atmosphere and the various carbonate species in the ocean (mostly HCO_3^-) must be maintained. Since the ocean contains about fifty times as much as the atmosphere, the ocean acts as a huge "buffer" for atmospheric CO_2. Excess CO_2 in the atmosphere is mostly dissolved to maintain the equilibrium expression: $P_{CO_2} = k[H_2CO_3]$. Of course, these equilibrium concepts can be tied to the results of students' study of the solubility of CO_2 in experiment *E-55*. About half of the excess CO_2 added to the atmosphere over the past century has already dissolved. It takes many decades, perhaps centuries, for complete equilibrium of the CO_2 concentration of the ocean with that of the atmosphere because of very slow mixing of bottom waters.

If climatic changes will, in fact, result from the increased CO_2 concentration (the so-called "greenhouse effect"), the social and economic implications will be staggering.

Students should be encouraged to maintain some perspective on this problem. Many other events are happening at the same time that CO_2 concentration is increasing, and some of them may counteract the greenhouse effect. For example, the various effects of particles released by human activities as well as by natural processes, such as volcanoes, may compensate for the increased CO_2 concentration. We don't know nearly enough about the causes of natural variations of climate, but we know that they are great enough to cause ice ages. Despite increased CO_2,

the temperature seems to have been dropping since 1940. Is the cooling the result of natural processes? Are we heading into another ice age? Can the increased CO_2 prevent the cooling? We don't know the answers to these questions, but they illustrate the great importance of further research into the influences of various natural and anthropogenic effects on climate. These are such long-term problems that we can't wait to see what's going to happen. If we do wait, by the time we find out it will be too late to take corrective actions. We have to understand the complex processes of the atmosphere and the oceans well enough to predict the results long before they occur.

E-45 GLOBAL EFFECTS OF PARTICLES

Predictions of the effects of atmospheric particles on global temperatures are much less certain than those made for CO_2. Depending upon the sizes and natures of particles, they can either warm the Earth's atmosphere or cool it. They can also have important secondary effects as condensation or freezing nuclei and affect cloudiness and precipitation.

Professor Helmut Landsberg at the University of Maryland has suggested that the most important effect of particles may occur when they are deposited on snow or ice (see Landsberg, H. E. "Man-made Climatic Change." *Science* 170:1265, 1970). The particles are much less reflective than the snow and ice; thus, they absorb some sunlight that would normally be reflected back into space, thereby producing a warming trend. For the best summary of current thought about global particle effects, consult "Inadvertent Climate Modification" (*The SMIC Report;* Cambridge, MA: MIT Press, 1971 paperback), *Man's Impact of the Global Environmental: Assessment and Recommendations for Action* (Wilson, C. L., and Matthews, W. H. Cambridge, MA: MIT Press, 1970), and "Atmospheric Carbon Dioxide and Aerosols: Effects of Large Increases on Global Climate" (Rasool, S. I., and Schneider, S. H. *Science* 173:138, 1971).

E-46 OZONE—SPRAY IT AWAY?

This section provides an excellent opportunity to discuss chemical kinetics of gas-phase reactions. Ozone is both created and destroyed by UV light.

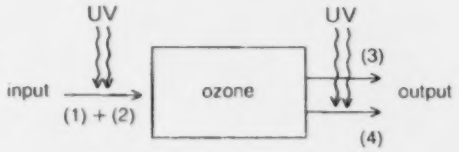
Creation: $O_2 + \text{UV photon} \longrightarrow O + O$ (1)

$O + O_2 \longrightarrow O_3$ (2)

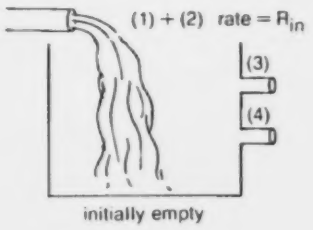
Destruction: $O + O_3 \longrightarrow O_2 + O_2$ (3)

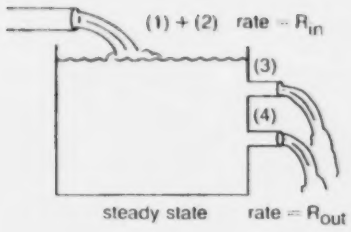
and $O_3 + \text{UV photon} \longrightarrow O_2 + O$ (4)

The formation and destruction of ozone is an example of *steady-state equilibrium*—not the kind of equilibrium that is attained when you place chemicals in a beaker and let them sit there until the concentrations of various species remain constant. In steady-state equilibrium, the species of interest, in this case ozone, is constantly formed by one set of reactions and destroyed by another set. Consider only reactions (1) to (4). Suppose a cubic meter of air in the stratosphere initially contains no ozone. Now allow it to be irradiated with a constant flux of UV light. Reactions (1) and (2) build up O_3 at a constant rate. As the concentration of O_3 increases, the rates of reactions (3) and (4) increase until they destroy O_3 at the same rate that it is being formed. From that time on, the concentration of O_3 remains constant as long as the UV flux remains the same—the steady-state equilibrium.



We can illustrate the principles involved in steady-state equilibria with a water reservoir. Reactions (1) and (2) are equated with a pipe supplying water to the reservoir. The water level builds up until it flows out of pipes representing reactions (3) and (4) at the same rate that it is flowing into the reservoir.





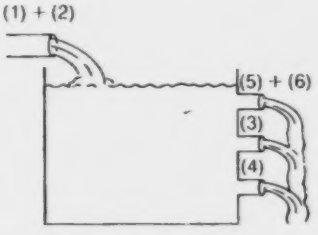
$R_{in} = R_{out}$ and amount in reservoir remains constant

The rates of reactions (1) through (4) are fairly well known, as is the UV flux in the stratosphere, so that one can calculate the steady-state O_3 concentrations at various altitudes. (The concentration is quite small below the stratosphere because O_3 in the stratosphere absorbs most of the UV light from the Sun.) If only reactions (1) to (4) are considered, the predicted steady-state ozone concentrations are much greater than observed concentrations. This means that we have neglected to include some reactions that destroy O_3. The main additional reactions are those involving NO, small amounts of which are thought to occur naturally in the stratosphere.

$$NO + O_3 \longrightarrow NO_2 + O_2 \qquad (5)$$
$$NO_2 + O \longrightarrow NO_2 + O_2 \qquad (6)$$
$$\text{Net } O_3 + O \longrightarrow 2\,O_2 \qquad (7)$$

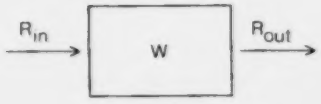
The addition of reactions (5) and (6) to our model of the stratosphere reduces the steady-state O_3 concentration (by about a factor of five in most calculations) to approximately the amounts actually observed in the stratosphere.

In our reservoir model, inclusion of reactions (5) and (6) are equivalent to the addition of another pipe to the reservoir. The outflow rate, R_{out}, increases, and the water level drops until R_{out} is again equal to R_{in} with less water in the reservoir at the new point of steady-state equilibrium.



The concept of a reservoir with inputs and outputs is a very useful description for many steady-state processes in the environment. Let's assume a reservoir with rates $R_{in} = R_{out}$ (in tons/year) and a steady-state amount of water W (in tons) in the reservoir. Each year a fraction R_{out}/W of the water in the water leaves the reservoir. Thus, the average length of time that a drop of water remains in the reservoir is W/R_{out}. This value is called the *residence time*, τ.

$$\tau = \frac{W}{R_{out}} \text{ or } \tau = \frac{W}{R_{in}}, \text{ since } R_{in} = R_{out} \qquad (8)$$



During the early 1970s, many scientists feared that the NO_x released in the stratosphere by a fleet of supersonic transports (SSTs) would destroy significant amounts of O_3 through reactions (5) and (6). This fear was one of several factors that halted development of the SST in the United States. Detailed studies of the rates of about one hundred reactions of importance in the stratosphere, however, have since indicated that the additional NO_x generated would probably have little net effect on the ozone layer. In the meantime, the Concorde SST (developed jointly by France and Britain) has been an economic failure and production has been halted.

During the course of studies on possible effects of the SST, another threat to the ozone layer was identified: the chlorofluoromethane compounds (CFMs) released from aerosol spray cans and used in refrigeration systems. Two CFM compounds were used as spray propellants, mostly for hair sprays and deodorants, trichlorofluoromethane (CCl_3F) and dichlorofluoromethane (CCl_2F_2), known as F-11 and F-12, respectively. These compounds have excellent properties. At room temperature F-11 and F-12 are liquids with high vapor pressures. As the vapor of these compounds is used to drive the product out of the can, the pressure inside the can is reduced, and

more of the liquid CFMs evaporate, building up the pressure again. These propellant compounds also are quite chemically inert; that is, they don't react with the product in the can.

Consumers were surprised to learn that most of the mass of material in the can was propellant; only a small fraction of the can's contents was product. Since CFMs are gases at normal pressures and temperature, they tend to remain airborne indefinitely. They are so chemically inert that no known reactions destroy them in the troposphere. They gradually make their way to the ozone layer of the stratosphere. Strong UV light from the Sun (not yet absorbed by the ozone layer) strikes these compounds and causes reactions that knock atoms of chlorine or fluorine off the CFM molecules.

$$CCl_3F(g) + \text{UV light} \longrightarrow CCl_2F(g) + Cl(g)$$
$$CCl_2F_2(g) + \text{UV light} \longrightarrow CClF_2(g) + Cl(g)$$

The liberated chlorine atoms then react with and destroy the ozone.

$$Cl + O_3 \longrightarrow ClO + O_2 \quad (1)$$
$$ClO + O \longrightarrow Cl + O_2 \quad (2)$$

Net reaction: $O + O_3 \longrightarrow 2\,O_2$

Note that these reactions form a cycle in which chlorine is used up in reaction (1) and regenerated in reaction (2). A single chlorine atom can go around the cycle thousands of times, destroying an ozone molecule each time.

Because of the potential threat to the ozone layer posed by the CFM propellants, federal and state agencies took action in 1977 to remove these compounds from further use.

CFM compounds are also used as the "working fluid" in nearly all refrigerators, freezers, and air conditioners. Using these compounds in this manner poses a serious leakage problem. The CFMs cause no problems while they are contained in these units. If the system develops a leak, however, the compound will escape. Special precaution must be taken to ensure that leakage does not occur. Unfortunately the cooling systems have been designed rather specifically for a working fluid having the properties of F-11 and F-12. As of this writing, satisfactory replacements for these compounds have not been developed.

ANSWERS TO PROBLEMS
(Student module page 87)

1. **a.** In general, the measures taken were: (1) use of low-sulfur fuels in highly populated areas; (2) construction of new fossil-fueled power plants well outside of urban areas; and (3) use of very tall emissions stacks on power plants and other large SO_2 sources.
   b. Yes. On a national scale, SO_2 concentrations have been reduced considerably in urban areas. Answers about local areas will vary.
2. **a.** Various animal studies have shown that sulfuric acid and sulfates interfere with breathing much more than SO_2, itself. The EPA CHESS studies also indicated that these compounds adversely affected human health, but these studies have been discounted.
   b. Sulfate levels have not been changed appreciably. The formation of sulfates is a slow process that occurs over long distances; therefore, it is a regional and not a local problem.
3. SO_2: b, c, d; CO: a; NO_x: a, b, c, d; Pb: a, d; hydrocarbons: a, e, f; particles: a, b, d.
4. **a.** NO_x, HC, CO, and sunlight.
   b. O_3
   c. Catalytic converters in the exhaust system are effective in speeding up the oxidation of CO and HC to CO_2 and H_2O.
5. CO is formed under reducing conditions (rich fuel/air mixture), while NO_x is produced under oxidizing conditions (lean mixture). Adjusting engine conditions to reduce one source of pollution usually increases the other. To remove both CO and NO_x from the exhaust system, CO must be oxidized to CO_2, while NO_x is reduced to N_2.
6. **a.** Increased CO_2 causes more of Earth's IR radiation to be trapped in the atmosphere, thus increasing its temperature.
   b. We're not certain of the overall effect, but probably the most important effect would be the increased scattering of UV and visible portions of sunlight back into space, thereby cooling atmospheric temperature.
7. $$\left(\frac{1.1 \times 10^6}{2}\right)(10) + \left(\frac{1.1 \times 10^6}{2}\right)$$
   $$= 6.0 \times 10^6 \text{ metric tons}$$
   This switch would cause a nearly six-fold increase.

EVALUATION ITEMS

These are additional evaluation items that you may wish to use with your students at various times during the preceding unit. The correct answer is indicated by shading.

1. Lead poisoning in children is most often caused by lead from:
   A. automotive exhaust
   B. toothpaste tubes
   C. chips of lead-based paints
   D. lead-chelating agents

2. Briefly explain why the presence of SO_3 in the atmosphere is a more severe problem when the air is humid.
   See section *E-27*

3. Which of the following is *not* a major source of SO_2 in the atmosphere?
   A. power plants
   B. volcanoes
   C. extraction of ores
   D. automobile exhaust

4. Which of the following plays little or no part in the production of photochemical smog?
   A. NO_2 **C.** $PbCl_2$
   B. UV light **D.** O_3

5. Photochemical smog is produced largely from the interaction of ultraviolet light with:
   A. NO_2 and hydrocarbons **C.** CO_2
   B. particulate matter **D.** SO_2

6. Which of these materials has the largest direct contribution to acid rain in unpolluted areas?
   A. Pb **C.** particulate matter
   B. CO_2 **D.** Hg

7. Which of the following is *not* a major air pollutant produced by automobiles?
   A. hydrocarbons
   B. ozone
   C. carbon monoxide
   D. nitrogen oxides

8. The major problem of diesel engine emissions is:
   A. carbon monoxide
   B. hydrocarbons
   C. sulfur dioxide
   D. particles

9. Ozone is made naturally when oxygen molecules are struck high in the stratosphere by:
   A. lead catalysts
   B. high-energy UV light
   C. chlorofluoromethane compounds
   D. all of the above

10. The greenhouse effect involves a worldwide increase of atmospheric:
    A. CO **C.** CO_2
    B. SO_2 **D.** NO_2

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SUGGESTED FILMS

Air Is for Breathing. Color, 29 minutes. Shell Film Library, 450 N. Meridian St., Indianapolis, IN 46204.
This study gives an analysis of what the main air pollutants are in the United States and of the principles needed to guide cooperative, systematic, and effective pollution control.

Air Pollution—the Facts. Color, 20 minutes. American Lung Association, 1740 Broadway, New York, NY 10019.
The foremost medical and scientific authorities from across the nation speak out on the subject of health and air pollution.

Cleaner Skies. Color, 18 minutes. Association Films, Inc., 600 Grand Ave., Ridgefield, NJ 07657.

Research to minimize pollution from aircraft engines involves measuring the concentration of pollutants in all layers of the atmosphere from sea level to the upper stratosphere.

ROX, SOX, NOX, the Anatomy of Air Pollution. Color, 12 minutes. American Lung Association, 1740 Broadway, New York, NY 10019.

Dramatic test-tube demonstrations illustrate the complex cause-and-effect relationships involved in air pollution.

Toward a Better Environment. Color, 28½ minutes. Department of the Army. (Please order films from the Army installation serving the state in which you live.)

This film shows investigations conducted by the United States Army Hygiene Agency in its efforts to control problems threatening our environment such as pesticide development, toxic effects of rocket fuels, occupational health hazards, sanitary engineering, and water and air pollution.

Energy: Use and Crisis

Energy use, or abuse, is such an enormous problem that there is no way that we can cover it in full detail in this unit. We've done our best to give students a feeling for the magnitudes of energy units, the sources from which our energy comes, the ways in which energy use is allocated, and the problems associated with the growth in demand for energy and the pollution resulting from its use. Energy demand, sources, and oil utilization problems will clearly change as the United States and other countries develop new methods of supplying energy, so it will be necessary for you to keep abreast of these developments by following news reports. We hope, however, that we've included all the basic information upon which to base coverage of future changes in the energy field.

E-47 FEAST TO FAMINE

A major problem facing teachers dealing with the topic of energy use may be that of convincing the students that *there is an energy crisis*. You may have to use your imagination and persuasive powers to accomplish this objective.

Miniactivity As we travel through the Universe in our "spaceship," our finite fossil-fuel supplies are being relentlessly, and wastefully, consumed. We cannot afford to let them run out without developing alternate sources. As an introduction to this section you may want to use the essay written by Isaac Asimov ("The Nightmare Life Without Fuel." *Time*, April 25, 1977) as the starting point for a very interesting discussion. The picture painted by Asimov is a grim shocker. You may want to point out that events don't have to turn out this badly, but they may unless several nations, especially the United States, make some clear decisions about plans for developing future energy sources and conserving energy. And we must start working towards these goals now! An important point Asimov stresses is that it *requires* energy to make new equipment to build additional energy production plants or to conserve energy. A considerable amount of energy is required if we want to build and install solar-energy units in each house, to develop and construct nuclear fission or fusion reactors, to build synthetic fuel plants, or to install additional insulation for houses. If our current energy sources dwindle too low before we get started on these projects, it will be much harder for us to recover.

Before going very far in the study of energy use, it is essential that students become familiar with the units of energy and power as defined in this unit. We have included several end-of-unit problems that involve the use and interconversion of various units of energy, but you may wish to make up some other ones for students to solve as you cover this section. It is also important for students to understand that although it is easy to convert the BTUs derived from burning a ton of coal into an equivalent amount of kWh of electrical energy on paper, the various forms of energy are not necessarily that easy to convert in practice. In particular, the conversion of heat to other forms of energy is always an inefficient process (see section *E-54*). You can also calculate how far a car would go on the energy contained in a lump of coal; however, this obviously can't be done in present-day cars. We take up this topic in more detail in later sections.

Miniexperiment It may give students a better feeling for the size of various units of energy if you have them carry out some simple tasks, such as lifting a weight,

running up stairs, and so forth, for which they can calculate the energy and power expended in several different units. A dramatic type of miniexperiment you can lead in conjunction with measurement of energy is one in which students measure their maximum power output over some finite time. For example, have students pull a toboggan (or other large, flat piece of wood or cardboard) heavily weighted with classmates over a high-friction surface such as the classroom floor. The toboggan can be pulled by a rope tied to a spring scale that is attached to the toboggan. The student pulling the toboggan should move as fast as he or she can at a steady rate over a measured distance between two points. **Caution:** *Only a physically fit student should be allowed to do this. Students must not be allowed to overexert themselves.* One student uses a stopwatch to measure the time it takes for the toboggan to cover the distance while a student on the toboggan reads the scale. Multiplying the force used by the distance traveled, you can calculate the energy expended, which, when divided by time, yields power. You might also consult with the physical education department to see if they have exercisers calibrated for energy measurements. According to David Wilson ("Getting in Gear: Human-Powered Transportation." *Technology Review* 82[1]:42 [1979]) top cyclists can develop about 1500 W (2 hp) briefly and can average about 375 W during a period of one hour.

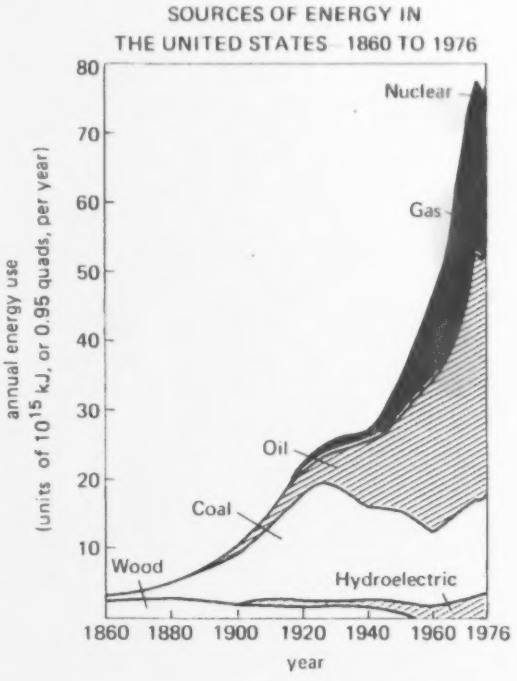
E-48 ENERGY SOURCES AND USES

The flow sheet of energy sources and uses in the student module, page 92, is a very useful diagram. It provides the student with a complete picture of the energy situation at a single glance. This general type of diagram is not unique to *The Delicate Balance;* variations have appeared in many books. Ours is somewhat special, however, because we have used SI units (10^{15} kJ/yr) throughout and we have attempted to separate residential uses from commercial uses. You might be interested in obtaining a copy of *Energy: A National Issue* (Murray, F. X. Washington, DC: The Center for Strategic and International Studies, Georgetown University, 1800 K Street NW, Washington, DC, 1976) which contains similar energy-flow diagrams showing units of millions of barrels of oil per day equivalent. This series of large, color-coded, fold-out flow diagrams for each decade is designed to be mounted on Plexiglas to form a three-dimensional model that shows changes in energy sources and uses over the past several decades, and projections of future uses.

An enlarged version of the table that appears on page 92 of the student module has been included on the following page. You may reproduce this page in classroom quantities or make an overhead projectual for use in your classroom discussion.

A surprising number of students (and adults!) think that all electricity is generated by waterpower created at dams. Make it clear with the flow diagram that only a fraction of our electricity comes from this source; the balance comes mainly from coal, oil, and nuclear steam-electric plants.

Energy use grew strongly from the mid-1800s until the 1930s, when energy consumption leveled off during the period of economic decline in the Great Depression. Demand then grew strongly again during and after World War II until the "first energy crisis" of 1973–1974, when it dropped slightly before rising again. Although our per capita consumption of energy in the United States is still far greater than it should be, we have conserved much energy since 1973. Our actual energy use in 1978 was about 8×10^{15} kJ below an extension of our pre-1973 energy-use curve.



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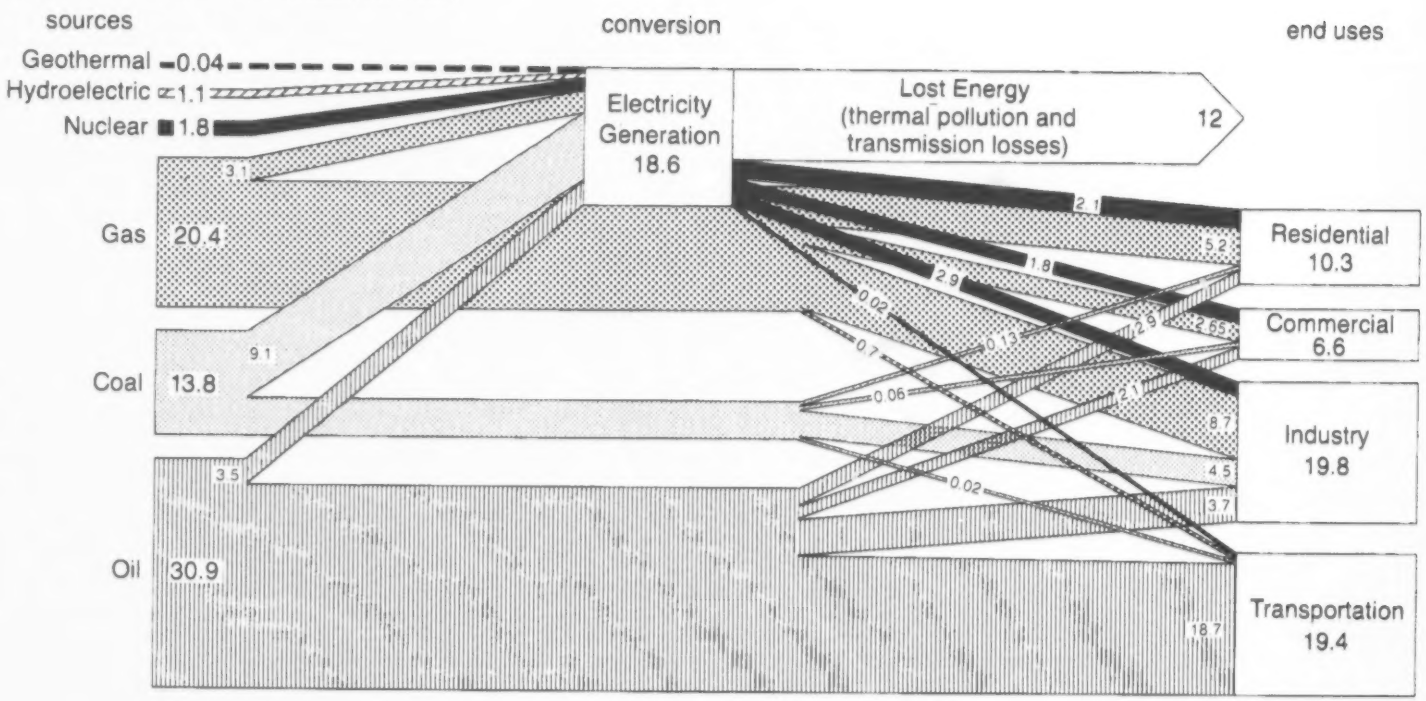
FLOW OF ENERGY IN THE UNITED STATES—1975
(units of 10^{15} kJ, or 0.95 quads, per year)



ENERGY-WATCH WORKSHEET

(for Miniexperiments *E-5* and *E-50*)

Name _____

Start Date _____ End Date _____ Number of Days _____

Number of Persons Living in Unit _____

Source of Energy (oil, gas, electricity)

Space Heating _____ Cooking _____

Energy Consumed

Electricity:	Final reading	____ kWh	
	Initial reading	____ kWh	
	Net energy consumed (Final - Initial)	____ kWh × 3600 J/kWh = ____ J	(1)
Natural Gas:	Final reading	____ ft^3	
	Initial reading	____ ft^3	
	Net energy consumed (Final - Initial)	____ ft^3 × 1.1 × 10^6 J/ft^3 = ____ J	(2)
Oil:	Initial volume	____ gal	
	Final volume	____ gal	
	Net change (Initial - Final)	____ gal	
	Amount purchased	____ gal	
	Total energy consumed	____ gal × 1.5 × 10^8 J/gal = ____ J	(3)

Gasoline:	*Auto 1*	*Auto 2*	*Auto 3*	*Total*
Gallons purchased	____ +	____ +	____	= ____ × 1.3 × 10^8 J/gal
				= ____ J (4)
Final odometer reading	____ mi	____ mi	____ mi	
Initial odometer reading	____ mi	____ mi	____ mi	
Net miles driven (Final - Initial)	____ mi	____ mi	____ mi	
Fuel economy (Divide net miles by gallons of gasoline purchased)	____ mpg	____ mpg	____ mpg	

Total energy used [add (1) through (4)]	=	____ J
Divided by number of users	=	____ J/person
Divided by number of days	=	____ J/person-day
Multiplied by 365 (number of days/year)	=	____ J/person/year

Our fuel sources have changed dramatically over the past century. In the late nineteenth century, wood still provided the major portion of our fuel supply. The early part of the twentieth century saw a large increase in coal use, especially for space heating. The initial growth of oil use was associated mainly with gasoline consumption by automobiles, but in the 1930s, oil began to replace the dirtier, more inconvenient coal for space heating uses. Coal use dropped again in the 1950s, in part because of uncertainties of supplies during long strikes by mine workers. The growth in the use of natural gas, the cleanest, most convenient fossil fuel, came as pipelines for its delivery were constructed. The use of hydroelectric plants to generate electricity has grown very slowly in recent years because most prime locations for dams have already been used.

E-49 THE OIL SQUEEZE

At this point you can start doing a variety of calculations regarding conservation of petroleum. Use problems 2 and 3 at the end of the unit as a starting point and make up other, related problems of your own. Since oil is used mainly for transportation, also consider alternate forms of transportation. (See section *E-43* of the teacher's guide for NPE values.)

You can make the students more aware of the part they play in the energy problem by noting the number of new drivers being added to the "pool" each year. Because of the post-World War II "baby boom" we've been adding about 4 million new drivers per year during the late 1970s, while only about 1.5 million drivers per year have died or retired from driving; this has given us a net increase of 2.5 million drivers per year. The *rate* of increase will drop because the number of new drivers from the baby-boom years peaked in 1980, and later classes of new drivers will be smaller. Increases in the number of drivers will continue, however.

Now, let's demonstrate how we can make a wild guess at the amount of oil needed to supply the 2.5 million additional drivers we have accommodated each year in the late 1970s. Let's assume there are about 150 million drivers in the pool. In answering problem 3, we determined that automobiles used about 7 mb/d of petroleum. The increase in petroleum use each year (assuming young people drive as much as average drivers, which may be a poor assumption) may be estimated as

$$\frac{2.5}{150} \times 7 \times 10^6 = 1.2 \times 10^5 \text{ or } 120\,000 \text{ b/d}$$

This figure may not sound too high, but over a decade, the increase in oil use would be 1.2 mb/d.

MINIEXPERIMENT
E-50 THE ENERGY-WATCH WRAP-UP

We suggest that you use a worksheet for student calculations. You may use a worksheet of your own design, or modify the worksheet we have supplied to make provision for local variations appropriate to your area, type of housing, and other differences. You may want to ask students other kinds of questions about the sizes and types of their houses, the installation of insulation, the use of air conditioning in warm weather, the types of appliances, the thermostat settings for heating and cooling, and so forth. Once you start to accumulate data, you can devise many interesting class projects that involve sorting the data by certain categories to identify factors that increase energy use. *(In order to avoid any embarrassment, remove names before distributing data to students.)* Don't forget the seasonal variation analysis suggested in section *E-5*.

ANSWER TO PROBLEM

(Student module page 99)

This problem is an extension of the project started in section *E-5*. With the use of the data given in this unit plus the energy conversion factors, encourage students to be as quantitative as possible about their energy-saving suggestions. You might find it useful to talk to managers at your local electric power company. They may be able to provide some interesting ideas about the "cost" of electricity during peak and off-peak hours and to make suggestions about time-of-day pricing policies to encourage more efficient off-peak use.

E-51 ENERGY AND THE ENVIRONMENT

No matter what source of energy we use, its use will cause some pollution of the environment. This is a fact we cannot deny. Our objective is simply to minimize the environmental impact of our energy use and to keep it from tilting the delicate balance we find in the "spaceship" Earth. Almost every day the news media bring to our attention another environmental catastrophe related to our efforts to satisfy our energy needs. The daily news contains reports of the buildup of fission waste products, gigantic oil spills, the easing of air-pollution standards to permit the use of coal, and so on.

In some cases such consequences may not be felt immediately, but sooner or later they will show up, perhaps unexpectedly. The Aswan Dam in Egypt is a case in point. Egypt is a nation made up of two very different regions: the desert and the Nile valley. Agriculture in Egypt is completely dependent upon the Nile. Building a giant dam on the Nile seemed like a good way to generate cheap electricity to accelerate the industrialization of Egypt, but agriculture was severely impaired as the dam interfered with the natural flooding cycle of the river. Now, twenty years later, a new consequence of the construction of this dam is being observed. The desert is advancing on the Nile valley faster than ever, while the fertile Nile delta is shrinking at the alarming rate of about 13 kilometers per year.

E-52 ENERGY FROM NUCLEI: FISSION

If your class is not going to cover *The Heart of Matter: A Nuclear Chemistry Module*, we suggest that you obtain both the student module and the teacher's guide, which provide much more detail on nuclear concepts than we include here. We have not included experiments in the nuclear sections of this module, but many are supplied in the nuclear-chemistry module.

Before engaging in the discussion of nuclear fission, you may wish to remind students of the origin of nuclear-energy release. The release of energy by nuclear fission is a confirmation of Einstein's theory of relativity that states that mass can be converted into energy (and *vice versa*). This is not done by taking a blob of matter and converting its mass entirely into energy. Instead, a large number of atoms (say 1 kg of mass) are converted into new atoms, each of which has a mass slightly less than that of one of the original atoms. You can calculate the energy released in nuclear transformations if you know the atomic masses (u) of the isotopes (*not* chemical atomic masses) involved. A typical radioactive decay is that of ^{24}Na, which has a 15-hour half-life.

$$^{24}_{11}Na_{13} \longrightarrow {}^{24}_{12}Mg^{1+}_{12} + {}^{0}_{-1}\beta^{-1}$$

This reaction is an example of the process of beta decay. $^{0}_{-1}\beta$ stands for a negative electron released from the nucleus of an atom. You can calculate the energy released from the masses of the neutral atoms by

$^{24}_{11}Na_{13}$:	23.990 962 u
$^{24}_{12}Mg_{12}$:	−23.985 042 u
mass converted to energy: (per atom)	0.005 920 u

0.005 920 u × 931.5 MeV/u

= 5.51 MeV (million electron volts)

When chemical reactions occur with the release of energy, mass is also converted to energy. But since most chemical transformations involve energies of about 1 eV (electron volt) per atom, we see that they are a million times smaller than those involved in nuclear transformations, so it is impossible to determine the masses of the reactants and the products accurately enough to observe the mass change. (In the combustion of coal, we would have to weigh 3000 tons to an accuracy of better than 1 g!)

Nuclear fission is a more complex nuclear reaction than beta decay. The target nucleus absorbs a neutron and splits into two massive fragments and a few neutrons. There are hundreds of ways in which the division can occur, with fragments of mass number anywhere between 70 and 165 being formed. However, neutrons and protons are conserved in fission, as you can check by adding the total number of each on both sides of the equation found at the beginning of section E-52 in the student module. When you add up the atomic masses of species on the left- and right-hand sides of the equation for a fission event, you find that the products have slightly less mass than the reactants, about 0.1 percent decrease of mass. In the fission of 1 kg of uranium, about 1 g of mass is converted to energy.

Gamma (γ) rays are just high-energy photons of light. In the same way that a photon of light is emitted by an atom when one of its electrons drops from one energy level to a lower one, a gamma ray is emitted when a nucleon (a neutron or a proton) drops from one level to another. That is, nuclei have various specific energy levels just as atoms do. Many beta decays leave the final nucleus in an excited state, which later decays emitting a gamma ray.

As noted in the student module, the big debate about the effects of radiation concerns the effects at very low dose rates where it is almost impossible to obtain meaningful data. Despite our poor knowledge of effects in this area, we should note that we know far more about the effects of radiation than about most things in our surroundings—for example, the hundreds of food additives we ingest every day. Certainly, we must make every effort to minimize the radiation doses to which people are exposed, but people tend to expend much more effort on debating these effects than they do in worrying about some more serious problems such as the radiation received from medical uses. It must be made clear to students that mutations are generally detrimental to human beings. They are confused by the fact that mutations help insect species develop resistance to insecticides. However, you must emphasize that, in order to achieve that kind of quick evolution of a species, about 99 percent of the species must be wiped out!

E-53 HAZARDS OF FISSION REACTORS

The construction of nuclear power plants is probably the most controversial topic in the entire energy/environment field. The controversy is fed by a widespread lack of understanding about the subject. We urge you to become as well informed as possible so that you can make valid assessments of the situation and lead your students to develop reasonable views about this issue. A good starting point would be *The Heart of Matter: A Nuclear Chemistry Module*. We also recommend Jeremy Bernstein's "Profile" of Hans Bethe—a distinguished theoretical physicist—a three-part series that ran in the December 3, 10, and 17, 1979 issues of *The New Yorker*. Part three, which contains a discussion of the energy crisis with emphasis on nuclear energy, is especially valuable reading. This series explains very complex, technical issues in terms easily understood by the layperson.

In addition to their fear of the unknown, opponents of nuclear energy probably also associate nuclear weapons with nuclear reactors. It is important to note the many beneficial uses to which nuclear energy has been put, especially in the diagnosis and treatment of various medical problems. For example, each year several million people are injected with radioactive elements as part of the performance of "scans" to detect tumors, to test thyroid function, and so forth. Much of our fundamental information about the behavior of elements and of compounds naturally occurring in the body was obtained by using compounds "labeled" with ^{3}H, ^{14}C, ^{131}I, ^{65}Zn, and other radioactive species.

Discussions of the hazards of nuclear energy may be broken down into four major areas.

1. the release of radioactivity from plants under normal operating conditions
2. the occurrence of accidents at nuclear plants serious enough to cause the dispersal of large amounts of radioactivity into the surroundings
3. the disposal of radioactive wastes generated by the operation of such plants
4. the theft of fissionable material (mainly plutonium) by terrorists or nations without the capacity to manufacture plutonium to construct nuclear weapons

The release of radioactivity during normal operation is the least serious of these problems. As we discussed in the student module, government regulations of nuclear reactor construction and operation are designed to keep exposure to radioactivity at levels far below those we receive normally from exposure to cosmic radiation and to naturally occurring radioactive elements. With very few exceptions, releases of radiation from nuclear reactors are well below the guideline values. Very few people are aware of the fact that coal-fired power plants release comparable or greater amounts of radioactivity into the atmosphere than do nuclear reactors. The burning of coal releases naturally occurring radioactive elements! The average radiation exposure from the nuclear power plant operation is far less than the

average dose received from medical applications of nuclear energy.

The possibility of accidents at nuclear power plants is a serious matter. A reactor that has been operating for a few months contains enough radioactivity to be lethal to thousands of people if it were released over a large, populated area. Because of this danger, the many lines of defense described in this section of the student module are employed. The construction and the operation of nuclear power plants are more carefully regulated than almost any other activity in the United States. You may contrast this regulation to the almost total lack of regulation, until quite recently, of the disposal of highly toxic chemical wastes. (See section *E-25*.) You might also compare this type of regulation to the way in which we entrust an unlicensed mechanic with fixing the brakes of our car.

One difficulty with this subject is that we are dealing with potential disasters that have an extremely low probability of occurring, but which would be lethal to very large numbers of people if they did happen. In 1975 a panel headed by Professor Norman Rasmussen of the Massachusetts Institute of Technology attempted to calculate the probabilities of many sequences of events leading to accidents of various magnitudes involving nuclear power reactors. The probability that reactor accidents resulting in large numbers of deaths will occur is extremely small. This probability is lower than that for other types of accidents such as the collapse of large dams, or the flooding from rivers, which can and sometimes do kill hundreds or thousands of people in the flood plains—yet people still live in flood plains. Although it is much more likely that a person would be involved in an airplane accident that might cause up to 500 deaths than in a nuclear reactor accident that could cause the same number of deaths, most people don't avoid traveling in airplanes. Train derailments that require the evacuation of hundreds of people because of the threat of toxic gas leakage from damaged tank cars occur frequently, but we don't ban the shipment of toxic chemicals on trains. Every year at least 40 000 people are killed in automobile accidents, but we continue to ride in cars. The average life expectancy of millions of Americans is shortened by the use of cigarettes, alcohol, and drugs, yet we permit these substances to be used. There are enormous protests, however, over the use of an energy source that benefits many people and carries a lower probability of causing death than any of the previously mentioned hazards.

Critics have charged that the Three Mile Island accident in Pennsylvania shows that the Rasmussen analysis was wrong. Is this accusation true?

The "bottom line" is that the safety systems of the Three Mile Island reactor worked to the extent that despite some lax maintenance procedures at the plant and some operator errors during the crisis, the plant did not blow up or release very much radioactivity. The accident's occurrence, however, was a clear warning that the safety procedures mandated by the Nuclear Regulatory Commission (NRC) needed to be revised in some areas and to be more vigorously enforced in general.

The problems posed by the disposal of radioactive wastes from nuclear-fission reactors are serious, but most likely solvable. Waste materials remain extremely radioactive for hundreds of years after they have been removed from fuel rods; these by-products must be prevented from entering our environment. The used fuel rods are first allowed to decay for about two years in water storage tanks adjacent to the reactor. After this period, the radioactive materials of long-term concern are the fission products with half-lives of about 30 years (such as ^{90}Sr and ^{137}Cs) and the actinide elements (such as plutonium), which have half-lives of up to 25 000 years. If the fuel rods are reprocessed (dissolved and chemically separated), the actinides can be returned to the reactor and "burned up"; that is, these elements can be fissioned by neutron capture. If reprocessing is done, this leaves only the fission products with 30-year half-lives, whose disposal is a much easier problem. Although the details of the eventual disposal method have not yet been decided, the nuclear-fission reactor wastes will probably be incorporated into a ceramic material and placed in salt-dome formations deep in the ground. The very existence of a salt dome indicates that no water penetrates the area; if there were water present, the salt would have dissolved and been carried away. Even if some radioactive wastes were to leak from their containers, most radioactive elements strongly attach themselves to clay deposits and, therefore, do not move very far through the ground.

The adhesion of most radioactive elements to minerals in the ground has been demonstrated by the existence of a natural "reactor" at Oklo in the Gabon Republic of Africa. About two billion years ago, a deposit of uranium was formed in such concentration at this site that a chain reaction started, and the uranium deposit behaved like fuel rods that had been in a reactor for probably 150 000 years, releasing about 15 000 MW-years of energy! How is all this known? All of the information has been inferred from anomalies in the isotopic abundances of the elements deposited at this site. The existence of the reactor was inferred from the finding that uranium from this deposit is slightly deficient in uranium-235, the fissionable uranium isotope, when compared to uranium found elsewhere on the Earth's crust. Abnormally large abundances of fission-produced isotopes of many other elements, such as the rare earths, are also found in this area.

The Oklo reactor is important to us because we can study the stable end products of the decay of the radioactive species produced in this natural "reactor" to see if the radioactive wastes migrated far from their original location. These studies indicate that there was almost no migration of rare earths, plutonium, and most other fission products. Half or more of the ^{90}Sr, which has a 28-year half-life, remained in place during its long decay. It is not known if ^{137}Cs, which has a 30-year half-life, migrated away, but it probably did because it is soluble.

It is very unlikely that natural reactors exist in modern times. It was much easier for such an entity to form two billion years ago because the isotopic abundance of uranium-235, which has a half-life of 700 million years, was then about 3 percent; the isotopic abundance of this species has now decayed to about 0.7 percent. Other natural reactors may have formed at this earlier time, but none has yet been found.

The danger posed by the theft of fissionable material from working reactors has probably been magnified far out of proportion. As the ^{235}U in the fuel rods undergoes chain reactions, the ^{238}U (the nonfissionable isotope that makes up over 99 percent of natural uranium) captures neutrons to form ^{239}U. This product decays with a half-life of 23 minutes to ^{239}Np, which in turn decays with a 2.3-day half-life, to $^{239}_{94}Pu$. The isotope $^{239}_{94}Pu$ is similar to ^{235}U and ^{233}U because it usually fissions when hit by a neutron; so it can be used, therefore, to run reactors or to make nuclear weapons. It is extremely difficult to separate ^{235}U from ^{238}U to make weapons, but, since ^{239}Pu is a different element, it can be separated chemically. If we are to have a long-term nuclear energy industry, it is essential that spent nuclear fuel rods be reprocessed to separate the heavy elements from fission products and that new fuel rods be made from the uranium and plutonium recovered. The uranium fraction contains so much ^{238}U that it can't be used to make weapons, but the relatively pure plutonium fraction can be used for this purpose. It is feared that if large amounts of plutonium are available, terrorists, organized crime groups, or countries without the capacity to produce their own plutonium might steal enough plutonium to make nuclear weapons. Because of this fear, President Carter placed a moratorium on fuel reprocessing during the late 1970s.

Although it is conceivable that a nation without plutonium-producing capabilities could fabricate a plutonium weapon by employing a sizable number of scientists and engineers in such a project for several years, it is unlikely that a terrorist or criminal group could do so. Plutonium is intensely radioactive and, thus, extremely toxic. The amount required to make a bomb requires a facility equipped for remote manipulation in which chemical treatment, metallurgy, and machining of the material could be done, unless the bomb manufacturers wish to be their own first victims. The construction of the bomb itself is a highly sophisticated problem because the critical mass of plutonium must be formed by implosion from carefully shaped, explosive charges.

To summarize the above discussion, we can say that the possibility that nuclear reactors may be involved in accidents is probably the major hazard associated with the production of nuclear energy. The key question is, "Are the hazards associated with producing nuclear energy so great that we should eliminate nuclear steam-electric plants from the mix of additional sources of energy and conservation measures to be included in the United States national energy plan for the 1980s and 1990s?" If we are going to expand our use of nuclear energy, that decision should be made as soon as possible so that scientists and engineers can proceed with improvements in the chemistry of reprocessing and waste

disposal and so that nuclear engineers can develop a new generation of reactors. If we're not going ahead with nuclear energy, then we can switch our efforts to the technologies involving the other energy sources chosen for expansion or development.

E-54 LOST HEAT—WHERE DOES IT GO?

Although thermal pollution is often linked with nuclear power plants, you must emphasize that all steam-electric plants waste about 60 percent or more of the heat used to generate the steam. This heat loss may be explained by the Second Law of Thermodynamics. The efficiency equation given in the student module, page 109, is commonly derived from the model of a reversible, frictionless heat engine operating in a Carnot cycle between reservoirs at temperatures T_1 and T_2. Only a fraction of the heat withdrawn from the high-temperature reservoir is converted to mechanical energy. The remainder is transferred to the low-temperature reservoir. Consult any good physical chemistry textbook for details.

If you have a fairly sophisticated group of students you can work in a qualitative discussion of the natural tendency of systems to change in directions that lead to more probable states, that is, to increase their randomness, a tendency often measured by the quantity known as *entropy*. Most students generally find this to be interesting. To illustrate this discussion, you may want to calculate the probability that all the molecules in the classroom will, at some instant, be found in the right half of the room, leaving a vacuum in the left half. The probability is $(\frac{1}{2})^N$, where N is the number of molecules in the room, or about 2.5×10^{25} × volume of room in cubic meters. See G. C. Pimentel and R. D. Spratley, *Understanding Chemistry* (San Francisco: Holden-Day, Inc., 1971, Chapters 8–10) for this sort of approach to randomness, entropy, and the spontaneity of changes.

One of the most lucid discussions of the Second Law and its implications for energy use is contained in Barry Commoner's *The Poverty of Power*, Chapter 2 (*The Poverty of Power—Energy and the Economic Crisis*. New York: Knopf, 1976). Commoner points out that we should calculate efficiencies of energy use from the point of view of the Second Law rather than from the premise of the First Law (conservation of energy) as we do now. Connected with this is the idea that different forms of energy have different "qualities." For example, electricity is a very high-quality energy source because it can be converted into other forms of energy with nearly 100 percent efficiency. Heat is a low-quality energy source, since there is a large loss when it is converted to other types of energy. We can conserve energy by carefully matching the quality of the energy sources we use to the particular needs the energy is used to meet.

The equation on page 109 of the student module also gives the theoretical efficiency of a "heat pump"—it is just the opposite of that for a heat engine. A heat pump uses mechanical energy to drive a Carnot cycle in the opposite direction, raising heat from the low-temperature reservoir to the high-temperature one. An air conditioner is a heat pump. It pumps heat from the cool room into the hot outdoor air. Some air conditioners can be reversed in winter time to pump heat from the cold outdoors to the warm room. Suppose the outside temperature is $T_2 = 263$ K (−10°C) and the inside temperature $T_1 = 298$ K (25°C), using the appropriate efficiency equation, we have

$$\frac{\text{heat transferred}}{\text{work done}} = \frac{T_2}{T_1 - T_2} = \frac{298}{298 - 263} = \frac{298}{35} = 8.5$$

This means that for every unit of electrical energy used, we transfer 8.5 units of heat into the house! That's much better than electrical-resistance heating, in which each unit of electrical energy produces a little less than one unit of heat. This is, of course, the theoretical efficiency. The actual efficiency would be considerably less than 8.5 units of heat. Houses in very mild climates are sometimes heated by heat pumps, but pumps don't work very well in really cold climates because of low heat-transfer rates in the outside heat exchangers at low temperatures.

It should be noted that automobile engines are also heat engines and are generally less efficient than steam-electric plants. Typical efficiencies of diesel, auto, and Wankel engines are 38 percent, 25 percent, and 18 percent, respectively.

In order to help alleviate the energy crisis and reduce thermal pollution, we must make strong efforts to use efficient energy-conversion devices.

For more on this, see "The Conversion of Energy." (Summers, C. M. *Scientific American*, September, 1971, pp. 148–160.)

We can also learn to treat warm water as a "resource-out-of-place." Warmer water sometimes creates good conditions for fish that are not adapted to the normally cooler water in the area. Thus, we may be able to create "fish farms" in warmed waters by introducing appropriate species. A good example of this is the oyster "farming" done by a commercial fishery on Long Island in New York. Oysters are hatched under controlled conditions in a hatchery. When the oysters are about six weeks old, they are placed on trays in a lagoon that receives heated water from a local power plant. The thermal discharge keeps the lagoon at 15°C to 32°C year-round, a temperature much warmer than the natural one of the waters of Long Island Sound. In this warm water, the oysters grow about five times as fast as they do under natural conditions. After about four months, the oysters are transferred to beds in Long Island Sound to complete their growth. Heated water, generated as a waste product by power plants, can also be used to heat buildings or swimming pools.

EXPERIMENT
E-55 THE FIZZ IS FAMILIAR

This experiment demonstrates the temperature dependence of the solubility of a gas in water. The effect with CO_2 is representative of the temperature effect with any gas.

Concept

- The solubility of a gas in a liquid is inversely related to the temperature.

Objectives

- Titrate a given volume of soda water with NaOH to a phenolphthalein end point.
- Interpret data in terms of relative solubilities of gases vs. temperature.

Estimated Time 45 minutes plus 15 minutes postlab discussion

Student Grouping Pairs

Materials

15 burets
15 buret holders
15 150-cm^3 beakers
15 thermometers
15 Bunsen burners
15 wire gauze
15 ring stands and rings
15 50-cm^3 graduated cylinders
1000 cm^3 0.1 M NaOH
3 bottles of soda water
ice
phenolphthalein indicator

Advance Preparation Prepare the solutions prior to class. For the 0.1 M NaOH solution, dissolve 4.0 g NaOH in distilled H_2O and dilute to a volume of 1000 cm^3. One bottle of soda water should be refrigerated ahead of time and poured into a large beaker in an ice bath; stir before handing out to students; two bottles are at room temperature. The phenolphthalein is in small dropper bottles.

Prelab Discussion Demonstrate titration techniques and the appearance of the end point if this was not done previously.

Laboratory Tips Have students titrate the solutions *quickly* so the temperature will not change too much. Suggested temperatures of the soda water: 20°C and 65°C.

Range of Results Students will find that the volume of NaOH is indirectly related to the temperature of the soda-water sample.

Postlab Discussion Discuss data. Point out the general solubility trend; as the temperature increased, less NaOH was required to titrate the sample because less CO_2 was present in the sample. Emphasize that this is true for all gases. The solubility of a gas in water is inversely related to the temperature of the water, although the relationship is more complicated that a simple 1/T dependence.

Optional Activity Convert the basic (pink) solution back to an acidic solution by using a straw to blow into the water. The CO_2 from the breath should restore the original colorless solution.

$$CO_2 + H_2O \qquad H_2CO_3$$

Answers to Questions

1. The solubility of CO_2 decreases with increasing temperature.
2. The partial pressure of CO_2 in an unopened bottle is much greater than the partial pressure of CO_2 in the atmosphere. After the bottle is opened, the dissolved CO_2 in the bottle will eventually come to equilibrium with the much lower partial pressure of CO_2 in the atmosphere.
3. See answer to question 2. At higher temperatures, CO_2 is less soluble in soda. At higher temperatures the rate of the reaction—the release of CO_2—is faster, making the fizzing more vigorous.
4. The warming of the water by thermal pollution reduces the solubility of its contained gases; in particular, the concentration of dissolved oxygen, which is needed by aquatic organisms, is decreased.

EXPERIMENT (Student Optional)*
E-E DISSOLVED OXYGEN

In this experiment, you will determine the concentration of the oxygen dissolved in several water samples.

Collection of Samples. Water samples must be carefully collected and stored to prevent contact with the air. Such contact will saturate the water with oxygen in a rather short time (about 10 or 20 minutes). The procedure suggested below should minimize the problem. Work carefully as you carry out the experiment.

Gently place the *capped* bottle as far below the surface of the water as you can reach. Unscrew the cap from the bottle and allow water to fill the bottle completely. Recap the bottle *while it is under water.*

For best results, you should add most of the reagents to the sample soon after collection (since organisms in the sample may use up some of the oxygen before you do the analysis). However, if you keep the sample bottle tightly stoppered and do the analysis within a day after sample collection, your results should be reliable. You now can test for the oxygen content of the water sample.

*The following experiment was originally in the student module, but it was removed because of a lack of space. However, you may want your students to do this experiment if you have the time.

Testing for Oxygen Content. First add 2 cm^3 manganese (II) sulfate ($MnSO_4$) solution to your sample by lowering the $MnSO_4$ dispensing buret tip directly into the sample bottle, *just* below the mouth. Then raise the buret; cap the sample bottle; rinse down the sides of the sample bottle with tap water. (**Caution:** *Do not allow these reagents to get on your hands.*)

Now add 2 cm^3 of alkali-iodide reagent to your sample by lowering the dispensing buret tip into your sample as before. Raise the buret; cap the sample bottle; rinse down the sides of the sample bottle. Mix by inverting or shaking the bottle several times. Allow the precipitate to settle. Then repeat this shaking and settling procedure at least two more times.

When settling has produced about 100 cm^3 of clear solution, remove the cap and add 2 cm^3 of concentrated sulfuric acid (H_2SO_4) from the dispensing buret. Cap the bottle and wash down the sides of the sample bottle. Mix by *gentle* inversion until the iodine is uniformly distributed throughout the bottle.

Carefully pour 100 cm^3 of the water solution into a 250-cm^3 Erlenmeyer flask. Titrate with sodium thiosulfate ($Na_2S_2O_3$) solution until a pale yellow color is evident. Add three or four drops of starch indicator and continue titrating until the solution color turns from blue to colorless. Record this final volume of $Na_2S_2O_3$ used in your titration. Pour another 100-cm^3 sample of the water solution into a clean flask and repeat the titration. Calculate results and average them for the two titrations.

Calculation of Results. The following chemical reactions represent the steps carried out in the experiment.

$$Mn(OH)_2(aq) + \tfrac{1}{2}\,O_2(g) \longrightarrow MnO_2(s) + H_2O(l) \quad (1)$$

$$MnO_2(s) + 3\,I^-(aq) + 4\,H^+(aq) \longrightarrow Mn^{2+}(aq) + I_3^-(aq) + 2\,H_2O(l) \quad (2)$$

$$I_3^-(aq) + 2\,S_2O_3^{2-}(aq) \longrightarrow 3\,I^-(aq) + S_4O_6^{2-}(aq) \quad (3)$$

Examining these equations will reveal that the amount of thiosulfate used is proportional to the amount of O_2 present in the water. To make an exact computation of the amount of O_2, however, it is necessary to examine the reactions more closely to determine the number of O_2 molecules per thiosulfate ion used. From reaction (1) we see that ½ mole of O_2 produces one mole of MnO_2. In reaction (2), one mole of MnO_2 produces one mole of I_2, which in reaction (3) produces one mole of I_3^- and one

mole of I_3^- used up two moles of $S_2O_3^{2-}$. Using $\hat{=}$ to denote equivalence, we can summarize these statements as

$$\tfrac{1}{2}\ O_2 \hat{=} MnO_2 \hat{=} I_2 \hat{=} I_3^- \hat{=} 2\ S_2O_3^{2-}$$

Thus, $1\ O_2 \hat{=} 4\ S_2O_3^{2-}$; that is, for every mole of O_2 present initially, we use four moles of $S_2O_3^{2-}$ in the final titration.

Your teacher will tell you the molarity $M(S_2O_3^{2-})$ of the thiosulfate solution.

The number of moles of $S_2O_3^{2-}$ used in the titration is given by

$$\text{moles of } S_2O_3^{2-} = \frac{V(S_2O_3^{2-}\text{cm}^3) \times M(S_2O_3^{2-})}{1000\ \text{cm}^3/\text{liter}}$$

We must divide this by 4 to obtain the number of moles of O_2; since the mole ratio is 1:4

$$\text{moles of } O_2 = \frac{V(S_2O_3^{2-}\text{cm}^3) \times M(S_2O_3^{2-})}{4000}$$

Since you used a 100-cm^3 (0.1 liter) sample of water, we must multiply the number of moles of O_2 by 10 to obtain the molarity of O_2, $M(O_2)$.

$$M(O_2) = \frac{V(S_2O_3^{2-}) \times M(S_2O_3^{2-})}{400}$$

Each mole of O_2 weighs 32 g or 32 000 mg; thus, to obtain the number of mg of O_2 per liter of H_2O, we multiply $M(O_2)$ by 32 000.

$$\text{mg } O_2/\text{liter } H_2O = V(S_2O_3^{2-}) \times M(S_2O_3^{2-}) \times 80$$

For example, if we used 7.5 cm^3 of 0.01 $M(S_2O_3^{2-})$ solution in the titration, this would give an O_2 concentration of

$$\text{mg } O_2/\text{liter } H_2O = 7.5 \times 0.01 \times 80 = 6.0\ \text{mg/liter}$$

In order to evaluate your procedure, two groups in the class should also do the experiment with two kinds of standards. One group should use a standard that is saturated with oxygen at room temperature. To prepare the standard, allow a beaker of water to stand open to the air for several hours. The other group should use a standard that has a minimum of oxygen in the water in the beaker. Boil water for several minutes and add chemicals before it has a chance to cool down.

At room temperature (about 20°C), the saturated sample should contain about 10 mg O_2/liter of water. The boiled sample should contain very little.

What is the quality of the water sample you collected for analysis? If it contains about 7 to 10 mg O_2/liter, it has sufficient oxygen for all life forms. If below about 5 mg O_2/liter, some game fish would probably not survive.

EXPERIMENT (Teacher's Notes)
E-E DISSOLVED OXYGEN

Concept

- Eutrophication can cause a decrease in the oxygen content of water.

Objectives

- Collect a sample of water.
- Determine the dissolved oxygen concentration in a sample of water.
- Calculate the oxygen concentration in a water sample, given data similar to that collected in this experiment.

Estimated Time *Prelab:* Distribute sample bottles; demonstrate the titration. *Lab:* One period; titrate samples. *Postlab:* One period; calculations and discussion.

Student Grouping Pairs

Materials

15 300-cm^3 collecting bottles, screw caps
15 burets
15 250-cm^3 Erlenmeyer flasks
3 dispensing burets
250 cm^3 of 2.15 M $MnSo_4$
250 cm^3 alkali-iodide reagent (see below)
100 cm^3 18 M (conc.) H_2SO_4
2000 cm^3 0.005 M $Na_2S_2O_3$
150 cm^3 starch indicator in dropper bottles

Advance Preparation Prepare solutions as follows:

$MnSO_4$(2.15M): Dissolve 120 g $MnSO_4 \cdot 4H_2O$ and dilute to a volume of 250 cm^3.
(This solute dissolves slowly—don't give up!)

Alkali-iodide: Dissolve 125 g NaOH in about 175 cm^3 cold water. Add to this solution 34 g NaI. Dilute to a volume of 250 cm^3.

0.005 M $Na_2S_2O_3$: Dissolve 2.44 g $Na_2S_2O_3 \cdot 5\ H_2O$ and dilute to 2000 cm^3. Add 1 g Na_2CO_3. Since thiosulfate is subject to bacterial growth, prepare it fresh every two weeks.

Starch Indicator: 1.0 g soluble starch, dissolved in enough cold water to make a paste. Pour into 150 cm^3 boiling water; boil until opaque. Store in dropper bottle; make fresh every two weeks.

Water Sample: Have students collect water and *cap the bottle under water;* collect from stream, lake, pond, basin of tap water, and so forth. The bottle must be capped under water so that the sample is not exposed to atmospheric oxygen. In order to be sure that the bottle is capped "airtight," you may suggest to your students that they place a piece of a "plastic sandwich bag" over the mouth of the bottle or jar and then screw on the cap. If you cannot supply water-sample bottles for the students, simply ask them to bring in bottles from home. The bottles should each have a 300–400-cm^3 capacity.

Prelab Discussion To calibrate the bottle have students carefully measure the volume of water their bottles will hold by using a graduated cylinder.

Demonstrate the sample-collecting method. Emphasize that any trapped air in the bottle will change the dissolved O_2 concentration. Point out to students that although water is 89 percent oxygen by mass, only dissolved oxygen is usable by fish and plants. It is only the dissolved oxygen that enters into reaction in this experiment.

Laboratory Tips The alkali-iodide reagent, $MnSO_4$, and concentrated H_2SO_4 must be handled with caution. One suggestion: have them dispensed from burets.

Students should lower the tip of the dispensing buret into the water sample before dispensing the reagent.

This titration is an "iodometric titration." Students must titrate their samples without the starch indicator until the samples become light yellowish brown in color, then add 2–3 cm^3 starch indicator. The samples will turn dark blue. The students should continue to titrate slowly until the dark blue color disappears. The end point is a "water-clear solution."

Range of Results By examining the previous series of reactions it is probably obvious that the amount of thiosulfate used is proportional to the amount of O_2 present in the water. However, to make an exact computation of the amount of O_2, it is necessary to examine the reactions more closely.

A good range of results is 5 mg/liter to 10 mg/liter. At concentrations below 5 mg/liter, the water is polluted. At a concentration of 10 mg/liter the water is saturated.

Postlab Discussion Discuss the preceding data and calculations. If students do not cap the bottles tightly, oxygen from the atmosphere will dissolve in the samples, for example. Ask why there is a range of results. Relate results to the water-sample *source*. The O_2 content is a function of the degree of pollution of the water-sample source.

ANSWERS TO PROBLEMS

(Student module page 112)

1. a. $T_1 = 350°C = 623\ K$

$T_2 = 15°C = 288\ K$

Maximum theoretical efficiency

$$= \frac{T_1 - T_2}{T_1}$$

$$= \frac{623 - 288}{623} \times 100$$

$$= 53.8 \text{ percent}$$

b. $1\ MW = 10^3\ kW = 10^3\ kJ/s = 3.6 \times 10^6\ kJ/h$, so

$500\ MW = 500 \times 3.6 \times 10^6\ kJ/h$

$= 1.8 \times 10^9\ kJ/h$

One ton of coal produces 2.5×10^7 kJ (see student module, section *E-47*, page 91), so we must burn

$$\frac{1.8 \times 10^9\ kJ/h}{2.5 \times 10^7\ kJ/ton} = 72\ ton/h,$$

at 100 percent efficiency. Since the efficiency is only 53.8 percent, however, we must actually burn

$$\frac{72}{0.538} = 134\ ton/h$$

c. The amount of heat wasted is

$(134 - 72)\ 2.5 \times 10^7\ kJ/h$

$= 1.55 \times 10^9\ kJ/h$, or $2.58 \times 10^7\ kJ/min$

Assuming that 1 liter of water = 1000 g and the specific heat = 4.184 J/g·°C, the amount of thermal energy required to raise the temperature of 1 liter of water 10°C is: $1000 \times 4.184 \times 10 =$

41.84 kJ. The amount of water needed to remove the excess heat of 2.58×10^7 kJ/min is

$$\frac{2.58 \times 10^7 \text{ kJ/min}}{41.84 \text{ kJ/liter}} = 6.17 \times 10^5 \text{ liter/min}$$

2. **a.** Total mileage per year

$= (1.5 \times 10^4 \text{ mi/automobile})(1 \times 10^8 \text{ automobiles})$

$= 1.5 \times 10^{12}$ mi/yr

Total gasoline consumption

$= (7 \text{ mb/d})(365 \text{ d/yr})(42 \text{ gal/b})$

$= 1.1 \times 10^{11}$ gal

Average "mileage"

$= 1.5 \times 10^{12} \text{ mi}/1.1 \times 10^{11} \text{ gal}$

$= 14$ mi/gal

b. $$\frac{1.5 \times 10^{12} \text{ mi/yr}}{(27.5 \text{ mi/gal})(42 \text{ gal/b})(365 \text{ d/yr})}$$

$= 3.6 \times 10^6$ b/d, or 3.6 mb/d

c. The savings would have been about 3.4 mb/d. The United States imported 7.3 mb/d in 1976, so only about 3.9 mb/d would have been imported.

3. **a.** $$\frac{(100 \text{ million automobiles})(2 \text{ gal/d/automobile})}{(42 \text{ gal/b})}$$

$= 4.8$ mb/d

b. 7.3 mb/d − 4.8 mb/d = 2.5 mb/d

4. **a.** $$\frac{68 \times 10^{15} \text{ kJ/yr}}{(210 \times 10^6 \text{ people})(365 \text{ d/yr})}$$

$= 887\,000$ kJ/(person × d), or 212 000 Cal/(person × d)!!

b. $\frac{212\,000}{2400} = 88.3$

EVALUATION ITEMS

These are additional evaluation items that you may wish to use at various times during the preceding unit. The correct answer is indicated by shading.

1. Name two sources of radiation, besides fission reactors, that affect people in their everyday lives.

   medical use of radioisotopes and X rays, natural radiation sources

2. A major problem of atmospheric fallout from nuclear-weapon explosions is the introduction of which radioactive species into our bodies?

   A. ^{143}Xe **C.** ^{140}Ba
   B. ^{90}Sr **D.** ^{131}I

3. The chemical behavior of ^{90}Sr is similar to that of:

   A. Al **C.** Ca
   B. I **D.** Zn

4. Give two reasons why thermal pollution can be considered a resource-out-of-place.

   Warm water can be used to irrigate crop lands or to heat buildings and swimming pools. See section *E-55*.

5. For each unit of energy available as heat, a typical steam-electric power plant run on fossil or nuclear fuel generates how many units of electrical energy?

   A. four **C.** one
   B. three **D.** one-third

6. Which nation has the highest per capita energy use?

   A. Japan **C.** USSR
   B. United States **D.** West Germany

7. In one second a 100-W lamp uses how much energy?

   A. 1.00 J **C.** 41.84 J
   B. 1.67 J **D.** 100 J

8. The metric unit of power, defined as a joule per second, is the:

   A. calorie **C.** newton
   B. quad **D.** watt

9. Beta-particle radiation is composed of high-energy:

   A. electrons
   B. gamma rays
   C. neutrons
   D. protons

10. Atoms of the same element having different masses are called:

    A. background radiation
    B. beta particles
    C. fission products
    D. isotopes

11. Which of these categories accounts for the greatest consumption of petroleum per year in the United States?

    A. electricity generation
    B. industrial

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C. residential
D. transportation

12. The half-life of a certain radioactive element is 3 days. How long will it take for its radioactivity to drop to one-fourth of its initial value?
A. 3 days C. 6 days
B. 4 days D. 12 days

13. A steam-power plant operates with steam at 790 K and cooling water at 310 K. Which of these calculations would give its theoretical efficiency?
A. 790 − 310 C. 310/790
B. 310/480 D. 480/790

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SUGGESTED FILMS

The Atom and the Environment. Color, 22 minutes. United States Department of Energy, Film Library, P.O. Box 62, Oak Ridge, TN 37830.
Used wisely, atomic energy may be an effective tool in the fight to preserve and restore this planet's threatened environment.

Consensus for Concern. Color, 27 minutes. United States Geological Survey, Branch of Visual Services, 303 National Center, Reston, VA 22092.
This film focuses on how the United States Geological Survey inspectors supervise oil and gas operations on the Outer Continental Shelf to maintain safety and to promote conservation of resources and the environment.

Nature's Forge. Color, 29 minutes. United States Department of Energy, Film Library, P.O. Box 62, Oak Ridge, TN 37830.
This film compares the effects on the environment of natural temperature extremes (e.g., caused by glaciers and volcanoes) and industrially caused extremes (e.g., excess heat produced by power plants).

Now That the Dinosaurs Are Gone. Color, 26 minutes. Tennessee Valley Authority, Film Services, Knoxville, TN 37902.
After explaining fuel depletion—by showing that the conditions that produced the earth's hydrocarbon fuels (*and* the age of dinosaurs) cannot be duplicated—this film explores potential alternative energy sources (hydroelectric, solar, geothermal, nuclear).

The Park. Color, 28 minutes. United States Department of Energy, Film Library, P.O. Box 62, Oak Ridge, TN 37830.
An examination of the on-site nuclear industry and its effect on the natural resources and living species around it.

Pollution Below. Color, 14 minutes. National Aeronautics and Space Administration. (Please order films from the NASA Regional Film Library serving the state in which you live.)
NASA's satellite cameras locate areas where unexpected pollution may precipitate dangerous situations.

Strip Mine Reclamation. Color, 17 minutes. Tennessee Valley Authority, Film Services Knoxville, TN 37902.
This film shows that, with proper planning and diligent follow-up, strip-mined land can be reclaimed, and sometimes even improved over its original state.

Three E's. Color, 28 minutes. Modern Talking Picture Service, 2323 New Hyde Park Rd., New Hyde Park, NY 10040.
A thorough, thoughtful review of the interrelationship between the "three e's" (energy, economics, and environment), the problems that have arisen in each area, and some possible solutions.

Wealth Out of Waste. Color, 27 minutes. Bureau of Mines, United States Department of the Interior, Motion Pictures, 4800 Forbes Ave., Pittsburgh, PA 15213.
This film identifies the variety of wastes generated in the United States today; examines research activities concerned with recycling of urban refuse and other wastes; and shows many useful products resulting from the waste-utilization research.

Future Sources of Energy

As we discussed in the preceding unit, serious shortages of conventional energy sources are beginning to occur. Unless we plan to reduce greatly our uses of energy, new sources must be developed. Nearly every week we read about some unusual source of energy; for example, there is a gentleman from England who runs his car on gas formed by the decomposition of chicken manure! When these unusual ideas are presented, they always sound wonderful, but if it were as easy as these proposals make it seem, we would have solved the energy crisis years ago. What are some of the most promising new energy sources? How much energy can they provide? What technological, economic, environmental, and other problems need to be solved before these new energy sources can make extensive contributions? We take a brief look at these questions in this unit.

E-56 HEAT FROM THE EARTH

As we note in section *E-56* in the student module, geothermal energy may provide very significant amounts of energy in certain areas, especially in areas of geological instability where there is volcanic and/or earthquake activity. Iceland, Italy, and California are examples of such areas. This type of energy source is often associated with serious problems. The Geysers Power Plant in California takes advantage of the dry steam that emerges from the wells in the Geysers field. The majority of geothermal deposits release hot water, however, which is much more difficult to handle. Such water usually has a high content of dissolved salts, that can cause severe corrosion of power-plant equipment. There is also the problem of disposing of the huge quantities of brackish water used by the plant; this water can't simply be released to the groundwater system. The geothermal water can be injected back into very deep holes. Some think the water might be

injected down into deposits of rocks hot enough to form steam— a more promising idea.

Other potential problems associated with geothermal energy are listed here.

- Sulfur-containing gases may be released with the steam or hot water from underground. Not only do such gases smell bad, but they add to the level of SO_2/sulfate air pollution.
- Naturally occurring radioactive isotopes such as ^{222}Rn and ^{214}Po may be released into the atmosphere when the steam or water is vented.
- The removal of water from geothermal deposits may cause instability and massive settling of the Earth's crust in the region of a *fumarole*, a hole where volcanic vapors and gases are released.
- Unusually large amounts of mercury vapor have been found in the atmosphere near the Geysers Power Plant in California.
- In some localities, the geothermal source might be exhausted after a rather unpredictable lifetime.

E-57 HARNESSING THE SUN

The idea of using solar power has enormous emotional appeal to all of us: it is clean, abundant, renewable, natural, and free. Solar energy is reducing our consumption of fuels, but it will probably not be used in the ways most people think. It seems unlikely that large, central solar steam-electric plants will be used except as pilot projects during this century. Such plants are just too expensive to build and to operate when we take into account the energy storage systems needed to provide reliable, continuous power throughout periods of cloudy weather and/or night. The conversion of heat to mechanical energy is very inefficient for solar systems with flat collectors, and installing movable mirrors to focus the light is very expensive.

Solar heating and cooling of individual buildings appear to be much more effective uses of solar energy than the generation of electricity in steam-electric plants. This is because individual installations do not go through the inefficient heat-to-mechanical energy conversion process. Over the next few years, we may see considerable numbers of solar systems installed in *new* buildings. Unless the prices of conventional fuels become astronomical, which is a good possibility, it is unlikely that owners of buildings with conventional heating and cooling systems will suddenly decide to replace their functioning systems with solar units.

A very important concept is often neglected in discussions of solar energy. This is the creation of passive solar systems; that is, designing buildings to take maximum advantage of the sunlight and the surroundings without installing pumps or rooftop solar energy collection systems. In the past, when energy was cheap, architects gave little thought to energy conservation. Today, with the use of good insulation, proper placement of windows, the use of window blinds, overhangs, and so forth, the heating and cooling energy requirements of many buildings have been reduced by up to 75 percent. 'Even in existing buildings not designed for energy conservation, considerable energy savings can be gained at a modest cost by adding insulation, awnings, reflective window shades, and so forth.

Solar photovoltaic cells are potentially a very important way to expand our use of solar energy. Such cells are made of semiconductor materials such as gallium arsenide (GaAs), cadmium sulfide (CdS), and pure silicon (Si), which are treated with controlled amounts of boron and phosphorus impurities. When photons with sufficient energy strike the cells, bound electrons in the cell material can be excited to the conduction band of the substance. If an electrical circuit is formed by connections made to the surfaces of the cell, the motion of these excited electrons causes a small electric current to flow through the circuit.

Large arrays of photovoltaic cells linked together to form solar batteries can provide large amounts of electrical power. Solar batteries provide power today for most orbiting satellites; they are used because they continue to produce power from sunlight indefinitely. Students are often confused about solar batteries. They may think that these batteries are similar to chemical flashlight batteries that eventually run down.

Solar batteries are not used much on the Earth because they are more expensive to make than are other energy producers. The technology for making solar cells is quite similar to that for making transistors, integrated circuits, and microprocessor chips for calculators and computers. Crystals of very pure materials must be grown and sliced

into thin wafers along certain crystal planes. These wafers are then treated with boron and phosphorous (in the case of silicon), and leads are attached to the cell surfaces. Such manufacturing operations require considerable labor by skilled workers, thus making the construction of solar cells very expensive. At present, the manufacturing cost is at least $5.00 per peak watt; that is, it costs $5.00 to produce cells that will generate 1 W of electric power when the Sun is nearly overhead on a cloudless day. Of course, this number of solar cells will produce far less power than the peak wattage when production is averaged over a 24-hour day. The capital costs of conventional steam-electric plants are in the neighborhood of $1000/kW peak capacity, or about $1 per peak watt. On this basis, it is assumed by experts that the cost of solar cells must be reduced to about $0.50 per peak watt before such devices will be widely used.

Solar energy proponents have urged the federal government to place large orders for solar cells at current prices for use in areas remote from power lines with the idea that mass production will bring the price down. Some solar cells have been ordered, but these orders are not as large as necessary to reduce the price. Government energy buyers fear that if they encourage mass production of solar cells now, suppliers will "lock-in" on the present design rather than searching for further breakthroughs that will ultimately bring down the price. Extensive research is in progress in an attempt to develop ways to manufacture solar cells more cheaply and/or to make more efficient cells. Most solar cells convert only about 10 percent of the light energy they receive to electricity; the remaining 90 percent is degraded to heat or is reflected from the cell's surface. The theoretical upper limit of efficiency for a solar cell is about 21 percent.

It would be very expensive to construct solar-powered houses with enough storage capacity to provide adequate power during the longest expected periods of cloudy weather. It would be far cheaper to build a solar-energy system that would handle most sunless periods, and to equip the house with a backup conventional energy system to meet energy needs during very unusual periods. This type of dual-source system would cause enormous problems for electric power companies, however, if a substantial fraction of their customers had such arrangements. The power companies would have to maintain a great deal of generating equipment that would stand idle most of the time so that they could meet the power demands of their solar-energy customers during long cloudy periods. For this reason, electricity rates for customers with solar-powered houses would probably have to be set much higher than those for customers with conventional energy systems.

Perhaps the most futuristic scheme for direct use of solar energy is one that calls for placing a satellite in an orbit that keeps it over a fixed point on the ground, but far enough out in space so that it can pick up sunlight most of the time. This satellite would supply energy to a huge array of solar cells and the electric power generated by the cells would be beamed to a receiver station via microwaves. The cost of such a system would be enormous, and some scientists are concerned about the environmental effects of such a powerful microwave beam.

MINIEXPERIMENT E-58 SUN POWER

This brief activity shows sunlight to be a major energy source.

Concepts

- The sun is a powerful source of energy.
- Solar batteries convert the energy of sunlight directly into electricity.

Objectives

- Harness sunlight to burn a hole in a piece of paper and to boil away a drop of water.
- Suggest uses of the Sun's energy.

Estimated Time 10 minutes

Student Grouping Pairs

Materials

15 magnifying glasses
15 pieces of paper (5 cm × 5 cm)
water in a dropper bottle
sodium sulfate decahydrate

Advance Preparation None

Prelab Discussion None

Laboratory Safety Caution students against focusing the Sun's rays on their skin.

Laboratory Tips You may have to show some students how to focus the sunlight in order to get a sharp beam (almost pinpoint) on the paper.

Range of Results Students will observe a burn mark or hole in the paper where the sunlight was focused. The drop of water will boil away. The sodium sulfate decahydrate sample will lose its water of hydration.

MINIEXPERIMENT

E-59 ELECTRICITY FROM THE SUN

This miniexperiment may be done as a class demonstration.

Concepts

- Energy can be converted from one form to another.
- Solar batteries can convert the energy of sunlight directly into electricity.

Objective

- To demonstrate that a solar cell converts sunlight into electric energy.

Estimated Time 15 minutes

Materials A suitable photovoltaic (photoelectric) cell may be purchased from a supply house such as Edmund Scientific Co., Barrington, NJ 08007. A voltmeter may be borrowed from the Physics Department at your school.

Advance Preparation Point out that the photoelectric effect was first explained by Einstein when he showed that metals needed a minimum amount of energy (threshold energy) to release electrons from the metal. Since energy is proportional to the frequency of radiation according to Planck's equation

$$E = h\nu$$

the ability to ionize is dependent upon the frequency of light and not upon its intensity.

Prelab Discussion None

Postlab Discussion The reading on the voltmeter should be highest when the angle between the Sun's rays and the photovoltaic cell is 90°C.

E-60 GROWING SOLAR ENERGY

The use of alcohol and other energy sources from biomass has much emotional appeal to people in the United States, especially in the rural midwest. A mixture of 10 percent ethyl alcohol and 90 percent gasoline, called *gasohol*, has been sold by a number of gasoline stations since 1979. This fuel can be burned in ordinary engines without modification.

Although gasohol is an interesting alternative fuel, its use saves little, if any, energy in the United States because of the way that the fuel is produced. United States agriculture is very energy-intensive. Farmers achieve high yields of grain per acre by extensive use of fertilizers, whose production requires a great deal of energy. In addition, much energy is used directly for cultivating, harvesting, drying, and transporting the grain crops. Finally, the distillation of alcohol from grain is usually done with heat generated by the combustion of oil or natural gas. Thus, using gasohol made from grain produces little net energy production and perhaps even a net loss. As a long-term policy, our use of grain for fuel if needed elsewhere in the world for food raises serious political and moral questions.

This is not to say that the use of biomass to generate energy has no future. Rather, certain steps must be taken to insure net energy gains when this source is used. For example, if the nongrain portions of a grain crop—the leaves and stalks—are used for energy, the energy to produce that biomass would also produce the grain, so that no additional energy would be needed. Solar stills, which use solar energy to provide heat for distillation, could be built. More of the drying of biomass could be done with sunlight and wind. If measures such as these are taken, a large net energy gain could be obtained from biomass; such a program is now in effect in Brazil. Whatever program is set up should be started only after a careful analysis has been made to determine the best "crops" for energy production. This analysis should take into account the

fertility of the soil, the climate, the competing uses of the land, and so forth. In many cases, the best energy return is obtained from growing sugar cane or sorghum. Brazil has made a heavy commitment to the use of alcohol as an energy source.

ANALYSIS OF ENERGY INPUTS AND OUTPUTS FOR THREE CROPS GROWN IN BRAZIL

Crop	Energy 10^6 kJ/hectare-yr* Input	Output	Net energy
Sugarcane	3.6	8.7	5.1
Cassava	2.75	3.19	0.44
Sorghum (using stems and grain)	5.9	11.1	5.2

*Based on J. G. da Silva et al., "Energy Balance for Ethyl Alcohol Production from Crops." *Science* 201:903 (1978).

Although cassava yields much less net energy per hectare than the other crops, it will be used extensively for other reasons; for example, because growing cassava requires more hand labor.

There are many other sources of biomass energy besides agricultural crops: trees, wastes from animal feedlots, or wastes from the paper and pulp industry. A secondary source of biomass is urban refuse. Some communities are developing power plants that burn a mixture of coal and combustible materials (mostly paper and cardboard) from urban trash to produce steam or electricity. If all of our refuse were used in this way, it would reduce United States use of fossil fuels for electric power generation by about 10 percent. Before this is done on a wide scale, however, emissions from plants burning refuse-derived fuel should be investigated carefully, since ordinary incinerators are known to release fairly large amounts of toxic metals such as mercury and cadmium.

One direct use of biomass for space heating is the use of wood in fireplaces and wood-burning stoves. Ordinary fireplaces, as most people use them, cause a net loss of heat because the draft of the fire draws more heat up the chimney than the fire adds to the room. Fireplaces with well-designed circulation systems or wood-burning stoves do reduce needs for other fuels for heating, and over a million wood-burning stoves have been sold in recent years. Burning wood may be a good way to reduce the uses of other energy sources in areas where there are good supplies of wood; however, forests must be well managed to prevent serious deforestation and the problems that accompany it—mud slides and soil erosion. Burning wood may not be a good solution to energy problems in heavily populated areas because it causes air pollution. Since the air supply is not fully adequate in wood-burning systems, incomplete combustion occurs and large amounts of fine carbonaceous particles are released. Some of the compounds borne by these particles are mutagenic. The particles may also cause serious visibility degradation. Environmentalists are often strongly attracted to the use of wood because it is "natural," but coal, oil, and gas are also natural sources of energy and, as we saw in section *E-53*, even the processes in nuclear reactors can occur in nature. However, natural things are not always benign—think of rattlesnakes and poison ivy, or aflatoxins and mushrooms!

Professor Melvin Calvin, who won a Nobel prize for his studies of the fundamental reactions of photosynthesis, has come up with an exciting "biomass" energy source: a plant called "euphorbia." This plant, a relative of the poinsettia, may be grown in hot, dry areas. It produces a hydrocarbon material similar to diesel fuel. The yield is about 10 bbl/acre of oil after a 7-month growing season, at an estimated cost of about $20/bbl. In 1980 this price was already below the world price for crude oil, so the euphorbia plant may have considerable potential if it can be grown on a large scale on land unsuitable for better uses.

E-61 FAR-OUT SOLAR SCHEMES

All the proposals discussed in this section of the student module are very interesting ideas, but most probably won't have a major impact on the energy crisis for many years except in some local areas with unusually high winds, tides, or other unusual conditions. One interesting idea that is not discussed in the student module is the generation of energy by using salinity gradients. You may recall from your physical chemistry courses that when pure water and a solution are separated by a semipermeable membrane, the pure water has such a strong tendency to pass through

the barrier to dilute the solution that it can raise a large pressure head on the solution side. The salinity of sea water relative to that of fresh water is enough to generate pressure to raise a column of water 240 m high when two bodies of water—fresh and salt—come together. In areas where large, fresh-water rivers meet the sea, the salinity gradient represents an enormous energy source. A flow rate of 1 m^3/sec of fresh water into the sea releases 30 MW! As yet, no practical device for extracting this enormous energy has been developed. You can calculate the pressure head that would be developed for water containing a concentration C (moles/liter) of dissolved substances relative to pure water: π (osmotic pressure) = CRT (in atmospheres—atm) where T = Temp (K), R = 0.082 liter · atm/mole · K and π is the pressure in atmospheres. One atm raises a column of water about 9.1 m and sea water has C = 1.1 M.

ANSWER TO PROBLEM

(Student module page 121)

The theoretical efficiency (ε) can be calculated from the equation

$$\varepsilon = \frac{T_1 - T_2}{T_1}$$

where T_1 = 27°C = 300 K and T_2 = 4°C = 277 K.

$$\varepsilon = \frac{300 - 277}{300} = 0.077 = 7.7\%$$

E-62 ENERGY FROM NUCLEI: FUSION

Nuclear fusion also offers the potential of almost limitless energy, but there are many hurdles in the way of its development. Breakthroughs based primarily on the Russian Tokamak principle have been covered in the press since 1971, but we still have a long way to go on magnetic-containment devices. We can't imagine that a working plant producing useful power will be constructed before 1990. There are essentially three criteria for successful operation (net energy production) of a nuclear fusion plant: plasma density, containment time, and temperature.

A small breakthrough in nuclear fusion development was recorded at Princeton University in 1980 when scientists obtained a temperature of *60 million kelvins* in their Tokamak. This temperature is close to the 100 million kelvins estimated necessary for sustained fusion reactions. The plasma density achieved by the Princeton team was 10^{13} particles/cm^3, only one order of magnitude below the estimated 10^{14} particles/cm^3 thought to be needed for sustained fusion. Their pulse times were less than 0.1 second, lower than the 1.0 second or longer deemed necessary to sustain a fusion reaction.

One bright spot regarding fusion is that the United States and the Soviet Union appear to be openly reporting developments in magnetic-containment work. By contrast, laser fusion seems to be under tighter wraps, perhaps because of possible military applications, for example, fusion weapons without fission "triggers." Some researchers are now investigating the possibility of using intense beams of electrons or heavy ions instead of laser beams.

E-63 SYNFUELS TO THE RESCUE?

The information provided in this section of the student module is fairly complete. Synfuels seem to be popular with politicians and with the general public because they give everyone the feeling that we're using domestic energy sources to solve the energy crisis. Most scientists are less enthusiastic. Although researchers feel that a strong research program is needed to develop processes for liquefying and gasifying coal and for unlocking petroleum from oil shale and tar sand deposits, they know that there are so many unknowns that it is premature to initiate plans to build full-scale synfuel power plants. Experts doubt that even an all-out development effort would produce more than 1 mb/d of petroleum by 1990.

Note that there are other approaches to energy utilization that would be equivalent to developing our capacity to convert coal to oil. Oil is used mainly to provide transportation. If we could convert an appreciable fraction of our vehicles to electric, battery-powered operation, however, we could use coal in its unconverted form to generate the electricity needed. Some additional power plants would be required to generate the extra electricity, but the number could be minimized by instituting time-of-day electricity pricing, which is used now in a few areas. In such systems, much lower rates are offered at night when most

power plants have unused capacity to encourage people to charge their batteries at that time.

E-64 WHAT'S THE ENERGY IN OUR FUTURE?

We suggest you emphasize that there will probably be no "magical" solution to the energy crisis. No single development, such as nuclear fusion or synfuels, will solve all our energy problems during this century. It is terribly important for political and economic reasons that the United States and other nations become less dependent upon oil supplies from the OPEC nations. Even if the price of crude oil were to stabilize or decrease, the "limits of growth" will eventually be encountered, so other sources will be needed. The sooner we prepare for that event, the better. Many chemists have also argued that petroleum is such a valuable starting material for the petrochemical industry that we shouldn't simply burn it, but we should conserve it as a chemical for future uses.

The solution to the energy crisis won't be dramatic—you probably won't see a newspaper headline stating, "The Energy Crisis Was Solved Today." Instead, the solution will be a series of small, almost imperceptible steps: families will decide to insulate their houses, the fuel economy of automobiles will gradually improve, the use of public transportation will grow, more new houses will be built to take advantage of sunlight, and so forth. New technological developments will be gradually introduced: cheaper solar cells, improved batteries for electric vehicles, solar stills for alcohol, highly efficient windmills, safer nuclear reactors, improved crops for biomass production, and so forth. Although progress on all these fronts may seem painfully slow, if we examine our energy-flow data in 1980 and again in 1990, we may be surprised to see great changes.

Many people suggest that we have another "Manhattan Project" or "Space Program" for energy development. That suggestion may have much merit for development of prototype devices, pilot-scale plants, or demonstration houses. But the results of such a project cannot suddenly be introduced into 80 million homes, nor can we scrap the 120 million automobiles now on the road. Recall that the Manhattan Project yielded exactly two atomic bombs and one test device. The space program placed about a dozen astronauts on the moon! Neither program mass-produced anything.

E-F FUEL CELLS AND THE "HYDROGEN ECONOMY"

For reasons of space, we have had to omit all discussion of fuel cells and the "hydrogen economy" from the student module. However, you may want to discuss this topic with your class if you have the time.

Fuel cells are not an energy source, but a device for converting chemical energy into other forms of energy efficiently and cleanly. You have probably electrolyzed water into hydrogen and oxygen gases. A hydrogen fuel cell simply reverses this reaction; in the cell, hydrogen and oxygen are combined and the energy released by the reaction is converted directly to electrical energy. This method of generating energy is at least twice as efficient as burning the hydrogen and using the heat to drive a steam-electric plant, which has the usual inefficiency of heat-to-mechanical energy conversions. Hydrogen fuel cells were used as the main energy source and as a source of water on the *Apollo* moon flights.

If we had a hydrogen economy, hydrogen would be distributed through pipelines just as natural gas is today. Your house would be equipped with fuel cells that would produce electricity. You would heat the house with the electricity or you might burn the hydrogen. The water produced by your fuel cells would also be very pure, so you could use it for drinking and cooking. Cars could be run very efficiently on hydrogen by using fuel cells to produce electricity and an electric motor to run the car. This way of fueling automobiles would be highly efficient, with an efficiency rating of 80 percent or more for obtaining mechanical energy from the chemical energy of hydrogen and oxygen gases taken from air. The car would emit no pollutants. To give the car a long-range touring capacity between fuel-cell recharges, the hydrogen would probably be carried as boiling liquid in a Dewar flask or as a solid hydride compound, since carrying large amounts of the gaseous form would require enormous pressurization to compress it into a reasonable volume. Remembering the tragic fire that

engulfed the hydrogen-filled Hindenberg Zeppelin, most people fear hydrogen will cause fires and explosions. Hydrogen is dangerous, but it is probably no more lethal than gasoline, which is an extremely dangerous fuel. In some ways, hydrogen is less dangerous than gasoline; its gaseous form is less dense than air, and it boils at a temperature near absolute zero. Thus, hydrogen quickly evaporates and leaves the area of an accident, whereas gasoline and its more dense vapors do not.

At present, adopting a hydrogen economy would not help solve the energy crisis because hydrogen is made by electrolysis of water, and this electricity would come from our present sources. Research on the development of chemical systems that would use solar energy to decompose water into hydrogen and oxygen gases is under way. Very few individual photons of sunlight have enough energy to break the bonds of water molecules and release hydrogen. What is needed is a cycle of several chemical reactions, each of which could be driven by the more abundant, lower-energy photons in sunlight. The net result of this series of reactions would be the formation of hydrogen gas. In a sense, we are trying to mimic the actions of the naturally occurring chlorophyll, a photosynthetic pigment present in green plants that absorbs the photons of sunlight. Through a series of steps, chlorophyll converts CO_2 and water into biochemical compounds, such as sugars and starch, that contain large amounts of chemical potential energy.

ANSWERS TO PROBLEMS

(Student module page 126)

1. a. $T_1 = 300°C = 573\ K$. $T_2 = 20°C = 293\ K$

$$\text{Efficiency} = \frac{573 - 293}{573} \times 100 = 48.9 \text{ percent}$$

b. $$\text{Area needed} = \frac{100 \times 10^6\ W}{250\ W/m^2} = 4 \times 10^5\ m^2$$

(*Note:* if plant has a 48.9 percent efficiency, the area needed is actually

$$\frac{4 \times 10^5\ m^2}{0.489} = 8.2 \times 10^5\ m^2 = 0.81\ km^2)$$

c. $(6\ kW / 100\ MW) \times 8.2 \times 10^5\ m^2 = 49\ m^2$

2. $$\frac{20\,000\ km}{(10\ km/liter)\ (1.5\ liter/m^2)} = 1300\ m^2$$

3. $$1000\ MW\left(\frac{100}{40}\right)\left(\frac{10^6\ W}{1\ MW}\right)\left(\frac{1\ J/s}{1\ W}\right)\left(\frac{1\ cal}{4.184\ J}\right)$$
$$\left(\frac{1\ Cal}{10^3\ cal}\right) \times \left(\frac{1\ ton}{2 \times 10^6\ Cal}\right)\left(\frac{1\ acre}{15\ tons}\right)$$
$$\left(\frac{3600\ s}{1\ h}\right)\left(\frac{24\ h}{1\ day}\right)\left(\frac{365\ days}{1\ yr}\right)$$
$$= 628\,000 \text{ acres/yr}$$

4. a. Total residential use in 1975 was 10.3×10^{15} kJ.
Using this figure,

$$\frac{(10.3 \times 10^{15}\ kJ/yr)\ (4 \text{ people/family})}{(365 \text{ days/yr})\ (220 \times 10^6 \text{ people})}$$
$$= 5.13 \times 10^5 \text{ kJ/(day/family of 4)}$$

b. 5.13×10^5 kJ/day

$$\frac{(5.13 \times 10^5\ kJ/day)\ (10^3\ J/kJ)}{(24\ h/day)\ (3600\ s/h)}$$

$= 5940$ J/s or 5940 W

The area needed is

$$\frac{5940\ W}{100\ W/m^2} = 59.4\ m^2$$

5. a. It would be more efficient to burn the gasoline in a power plant first (overall efficiency $0.33 \times 0.80 = 0.264$) rather than in the automobile directly (overall efficiency = 0.25).

b. Cost of using gasoline:

$$\frac{(\$1.20/gal)\ (40\ mi/day)}{20\ mi/gal} = \$2.40/day$$

Cost of using electricity:

[($0.05/kWh) (2 gal/day) ($1.3 \times 10^8$ J/gal)
× (0.25 engine efficiency)]
÷ [(0.80 electric engine efficiency)
× (3 600 000 J/kWh)]
= $1.13/day

EVALUATION ITEMS

These are additional evaluation items that you may wish to use at various times during the preceding unit. The correct answer is indicated by shading.

1. Why is nuclear fusion not a commercially useful energy source?
   - **A.** Not enough raw materials are available.
   - **B.** Our technology is still inadequate.
   - **C.** The pollution produced by this method of production exceeds acceptable limits.
   - **D.** The radioactivity produced is excessive.

2. Geothermal energy is derived from heat contained in rocks under the Earth's surface. Which of the following are current uses of this source of energy?
   - **A.** heating homes
   - **B.** melting glaciers
   - **C.** powering aircraft carriers
   - **D.** producing electricity

3. Geothermal power plants withdraw large quantities of steam from the Earth which may cause environmental problems. Describe some of these problems.

   Sulfurous gases, mercury vapor, and salt-containing water droplets may be released with the steam. These effluents must be controlled to prevent pollution.

4. Which feature of solar energy is a disadvantage if the Sun is to be harnessed as the major energy source?
   - **A.** The Sun is a renewable energy source.
   - **B.** The Sun is a diffuse source of energy.
   - **C.** The Sun is a clean energy source.
   - **D.** Sunlight reaches the Earth in abundant quantities.

5. A primary product formed by coal gasification is:
   - **A.** carbon dioxide
   - **B.** methyl alcohol
   - **C.** sugar
   - **D.** water

6. Which of these energy supplies does not have the Sun as its original source?
   - **A.** coal
   - **B.** nuclear energy
   - **C.** petroleum
   - **D.** wind power

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Clean Energy. Color, 25 minutes. Association Films, Inc., 600 Grand Ave., Ridgefield, NJ 07657.
Presents an emphatic view of solar energy expansion as the only long-range alternative if society chooses minimized future uses of nuclear energy and extensive conversion technologies.

Energy Vs. Ecology . . . The Great Debate. Color, 27½ minutes. Modern Talking Picture Service, 2323 New Hyde Park Rd., New Hyde Park, NY 11040.
This film discusses the ways developed to utilize coal, an abundant energy source, *without* disrupting the environment.

Geothermal—The Roaring Resource. Color, 22½ minutes. California Department of Water Resources, Graphic Services, P.O. Box 388, Sacramento, CA 95802.
A presentation of the search for a supplemental energy and water source from the Earth's underground reservoirs of superheated steam.

Here Comes the Sun. Color, 15 minutes. ERDA Film Library, P.O. Box 62, Oak Ridge, TN 37830.
Solar energy "goes to school" as students, teachers, and communities in Massachusetts, Maryland, Virginia, and Minnesota examine different aspects of solar heating.

A Land For All Reasons. Color, 23 minutes. Association Films, Inc., 866 Third Ave., New York, NY 10022.
Documentation of the Bureau of Land Management function and its specific concern with the shale-oil land around Rifle, Colorado.

The Winds of Change. Color, 5½ minutes. McDonnell Douglas Corp., St. Louis Library, Dept. 091, P.O. Box 516, St. Louis, MO 63166.
Describes how electrical power can be derived from the wind by the use of advanced-concept windmills.

Where Do We Go from Here?

In addition to the points made in the summary in the student module, we also make the following observations.

- The energy crisis has grown worse. Fuel shortages are putting pressure on governmental agencies to relax their environmental quality guidelines. Recent agency rulings have permitted continued use of polluting fuels, and delayed and weakened auto-emissions standards because some pollution controls reduce engine efficiency.
- There are some hopeful, long-range developments in United States energy policy. Some federal governmental reorganization has taken place, and a Department of Energy has been created at the Cabinet level.
- More attention has been focused on food additives and related products. The hormone-like growth additive diethylstilbesterol (DES) can no longer be used in the feed of slaughter animals because of its carcinogenic properties. Many dyes and coloring agents are under careful investigation and some have been banned.
- Waste recycling does not seem to be catching on very fast. In fact, many recycling centers operated by volunteers have closed. We must make greater efforts to turn urban wastes and sewage, large "resources-out-of-place," into "resources-in-place." Despite its success in some areas, there is still a great deal of opposition to legislation banning throwaway bottles.
- By the time you teach this course, there will undoubtedly be many more developments for you to discuss with the students. To keep up-to-date, you may want to continue clipping articles and keeping files on many environmental topics.

Appendix

Safety

SAFETY IN THE LABORATORY

Proper conduct in a chemistry laboratory is really an extension of safety procedures normally followed each day around your home and in the outside world. Exercising care in a laboratory demands the same caution you apply to driving a car, riding a motorbike or bicycle, or participating in a sport. Athletes consider safety measures a part of playing the game. For example, football players willingly spend a great deal of time putting on equipment such as helmets, hip pads, and shoulder pads to protect themselves from potential injury.

Chemists must also be properly dressed. To protect themselves in the laboratory, they commonly wear a lab apron or a coat and protective glasses. Throughout this course you will use similar items. Hopefully their use will become second nature to you, much as it becomes second nature for a baseball catcher to put on a chest protector and mask before stepping behind home plate.

As you read through a written experimental procedure, you will notice that specific hazards and precautions are called to your attention. Be prepared to discuss these hazards with your teacher and with your fellow students. Always read the entire experimental procedure thoroughly before starting any laboratory work.

A list of general laboratory safety procedures follows. It is not intended that you memorize these safety procedures but rather that you *use* them regularly when performing experiments. You may notice that this list is by no means complete. Your teacher may wish to add safety guidelines that are relevant to your specific classroom situation. It would be impossible to anticipate every hazardous situation that might arise in the chemistry laboratory. However, if you are familiar with these general laboratory safety procedures and if you use common sense, you will be able to handle potentially hazardous situations intelligently and safely. Treat all chemicals with respect, not fear.

GENERAL SAFETY GUIDELINES

1. Work in the laboratory only when the teacher is present or when you have been given permission to do so. In case of accident, notify your teacher immediately.
2. Before starting any laboratory exercise, be sure that the laboratory bench is clean.
3. Put on a laboratory coat or apron and protective glasses or goggles before beginning an experiment.
4. Tie back loose hair to prevent the possibility of its contacting any Bunsen burner flames.
5. Open sandals or bare feet are not permitted in the laboratory. The dangers of broken glass and corrosive liquid spills are always present in a laboratory.
6. Fire is a special hazard in the laboratory because many chemicals are flammable. Learn how to use the fire blanket, fire extinguisher, and shower (if your laboratory has one).
7. For minor skin burns, immediately immerse the burned area in cold water for several minutes. Then consult your teacher for further instructions on possible additional treatment.
8. In case of a chemical splash on your skin, immediately rinse the area with cold water for at least one minute. Consult your teacher for further action.
9. If any liquid material splashes into your eye, wash the eye immediately with water from an eyewash bottle or eyewash fountain.
10. Never look directly down into a test tube—view the contents of the tube from the side. (Why?)
11. Never smell a material by placing your nose directly at the mouth of the tube or flask. Instead, with your hand, "fan" some of the vapor from the container toward your nose. Inhale cautiously.
12. Never taste any material in the laboratory.
13. Never add water to concentrated acid solutions. The heat generated may cause spattering. Instead, as you stir, add the acid slowly to the water or dilute solution.
14. Read the label on a chemical bottle at least *twice* before removing a sample. H_2O_2 is not the same as H_2O.
15. Follow your teacher's instructions or laboratory procedure when disposing of used chemicals.

This symbol represents three of the common hazards in a chemistry laboratory—flame, fumes, and explosion. It will appear with certain experiments in this module to alert you to special precautions in addition to those discussed in this Appendix.

Metric Units

PHYSICAL QUANTITY	SI BASE OR DERIVED UNIT		OTHER UNITS	
	NAME	SYMBOL AND DEFINITION	NAME	SYMBOL AND DEFINITION
length	meter*	m	kilometer	$1\ km = 10^3\ m$
			centimeter	$1\ cm = 10^{-2}\ m$
			nanometer	$1\ nm = 10^{-9}\ m = 10^{-7}\ cm$
area	square meter	m^2	square centimeter	$1\ cm^2 = 10^{-4}\ m^2$
volume	cubic meter	m^3	cubic centimeter	$1\ cm^3 = 10^{-6}\ m^3$
			liter	$1\ l = 10^{-3}\ cm^3$
mass	kilogram*	kg	gram	$1\ g = 10^{-3}\ kg$
time	second*	s		
amount of substance	mole*	mol		
concentration	moles per cubic meter	mol/m^3	moles per liter	$1\ mol/l = 10^3\ mol/m^3$
			molar concentration (molarity)	$1\ M = mol/l$
Celsius temperature			degree Celsius	°C
thermodynamic temperature	kelvin*	K		
force	newton	$N = kg \cdot m/s^2$		
pressure	pascal	$Pa = N/m^2 = kg/(m \cdot s^2)$	centimeter of mercury	$1\ cm\ Hg = 1.333 \times 10^3\ Pa$
			atmosphere	$1\ atm = 1.013 \times 10^5\ Pa$ $1\ atm = 76.0\ cm\ Hg$
energy	joule	$J = N \cdot m = kg \cdot m^2/s^2$	calorie	$1\ cal = 4.184\ J$

*SI base unit, exactly defined in terms of certain physical measurements.

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Module Tests

Two module tests follow: one to test knowledge-centered objectives and the other to test skill-centered objectives. If you choose to use either or both of these module tests as they are presented here, duplicate copies for your students. Or, you may wish to select some of the questions from these tests that you feel apply to *your* chemistry course and add additional questions of your own. Either way, make sure that the test you give reflects your emphasis on the chemistry that you and your students experienced in this module.

The skill-centered test will require that you set up several laboratory stations containing materials for your students to examine or to work with. You may wish to add additional test items to round out the types of skills you and your students have worked on.

Answers to the test questions in this section are provided. If you wish to use a standard-type answer sheet for this test, one is provided in the appendix of this teacher's guide.

ANSWERS FOR KNOWLEDGE-CENTERED MODULE TEST

1. A; **2.** D; **3.** D; **4.** A; **5.** C;
6. B; **7.** C; **8.** D; **9.** C; **10.** A;
11. B; **12.** D; **13.** B; **14.** B;
15. B; **16.** A; **17.** D; **18.** B; **19.** C;
20. B; **21.** D; **22.** A; **23.** D; **24.** C;
25. C; **26.** C

THE DELICATE BALANCE
Knowledge-Centered Module Test

1. Thermal pollution is the release of
   A. waste heat into the environment.
   B. solid pollutants into the environment.
   C. radioactive pollutants into the environment.
   D. gaseous pollutants into the environment.

2. Our present energy needs are being supplied by
   A. hydroelectric power plants.
   B. fossil-fuel burning power plants.
   C. nuclear power plants.
   D. all of the above

3. The products of a nuclear-fission reaction
   A. are mostly stable nuclides.
   B. generally have too many protons to be stable.
   C. decay predominantly by α-particle emission.
   D. are highly radioactive, decaying primarily by β and γ decay.

4. A constructive method of employing thermal pollution is its use in
   A. fish farming.
   B. cooling office buildings.
   C. producing algae blooms.
   D. all of the above

5. The main purpose for adding phosphates to detergents is to
   A. bleach clothing.
   B. dissolve grease.
   C. complex metal ions of hard water, preventing their precipitation with detergent molecules.
   D. all of the above

6. Haze that reduces visibility is caused by
   A. an excessive warming of the air.
   B. particulate matter suspended in air.
   C. an excessive amount of CO_2 in the air.
   D. an excessive amount of NO in the air.

7. The serious hazards of nuclear-fission reactors include the danger of
   A. very high radiation doses for all workers within several hundred meters of the reactor during normal operations.
   B. a nuclear explosion of the reactor.
   C. leaks from tanks in which the highly radioactive wastes from fuel reprocessing are stored.
   D. all of the above

8. The pollution of the air by SO_2 results in
   A. deterioration of monuments and buildings in cities.
   B. stripping the leaves from vegetation.
   C. formation of sulfates that may cause respiratory problems in humans.
   D. all of the above

9. A metal which is most toxic to humans is:
   A. Mg B. Na C. Hg D. Ca

10. In many American cities, a major source of SO_2 pollution in the air is
    A. fossil-fuel power plants.
    B. nuclear-fusion power plants.
    C. automobiles.
    D. natural gas ranges.

11. During eutrophication, phosphates in streams and lakes
    A. are highly toxic to most aquatic species.
    B. are essential nutrients for growth of algae.
    C. release large amounts of oxygen.
    D. increase the hardness of the water.

12. An alternative to the use of chlorinated hydrocarbons for insect control is the
    A. development of synthetic sex attractants.
    B. breeding of new crop species having greater resistance to attack by insects.
    C. introduction of predators of the particular insect from other parts of the world.
    D. all of the above

13. The major sources of lead in the air of a typical American city are
    A. oil-burning furnaces.
    B. automobiles.
    C. fossil-fuel power plants.
    D. roasting of lead sulfide ore.

14. Lead pollution presents a very serious threat to humans because
    A. it causes their bodies to radiate too much heat.
    B. it affects their brain and nervous system.
    C. it causes skin cancer.
    D. all of the above

15. A thermocline in a lake is an invisible barrier of water that
    A. has a much greater density than the layers of water above and below.
    B. prevents mixing between the layers of water above and below.
    C. has a much higher temperature than the layers of water above and below.
    D. all of the above

16. Nuclear fission is
    A. the splitting of heavy nuclei into two nuclei of roughly equal mass.
    B. the formation of a heavier element from lighter ones.
    C. the splitting of heavy nuclei into uranium nuclei.
    D. none of the above

17. Thermal pollution is responsible for
    A. lowering the algae reproduction rate in thermally polluted water.
    B. lowering the phosphate concentration in thermally polluted water.
    C. raising the dissolved CO_2 content in thermally polluted water.
    D. lowering the dissolved oxygen content in thermally polluted water.

18. Determine which of the following four statements are true.
    1. Newspapers are biodegradable.
    2. Newspapers are nonbiodegradable.
    3. Polyethylene bottles are biodegradable.
    4. Polyethylene bottles are nonbiodegradable.
    A. 1 and 3 C. 2 and 3
    B. 1 and 4 D. 2 and 4

19. The "greenhouse effect" involves a worldwide increase of:
    A. O_3 B. NO_2 C. CO_2 D. SO_2

20. Geothermal energy is referred to as a "relatively clean" energy source. One disadvantage of this energy source is that
    A. it contains an excessive quantity of lead.
    B. massive settling of the Earth's crust may occur in the region of the geothermal source.
    C. it contains CO.
    D. all of the above

21. Which of the following is a major demand of energy for society?
    A. transportation
    B. industry
    C. household
    D. all of the above

22. Global SO_2 pollution of the air could be reduced by
    A. replacing fossil-fuel power plants with nuclear-fission plants.
    B. placing fossil-fuel power plants near the ocean.
    C. placing fossil-fuel power plants in the country.
    D. all of the above

23. One problem presented by the further use of pesticides is that they
    A. are very toxic to crops.
    B. are biodegradable.
    C. harden our water supplies.
    D. concentrate in species at or near the top of the pyramidal food chain.

24. One thing that can be done to slow the aging of our lakes is to
    A. produce artificial thermoclines.
    B. cut the flow of carbonates into our waterways.
    C. halt eutrophication.
    D. cut the flow of nitrogen oxides into our waterways.

25. One of the conditions necessary to produce smog similar to the type that is experienced over Los Angeles is
    A. an excessive amount of SO_2 in the air.
    B. a very windy day.
    C. a temperature inversion.
    D. an excessive amount of Pb in the air.

26. One of the ions responsible for hard water is:
    A. Na^+ B. Cl^- C. Ca^{2+} D. H^+

Skill-Centered Module Test

Using the skill-centered test items will require certain advance preparations on your part. The numerals in the following list indicate the items for which you will have to prepare special laboratory stations. Be sure to test each of the lab stations before allowing students to determine the answers to the skill-centered items. When students are ready to answer these questions, they should go to the numbered station and follow the directions that are given there and in the printed test item. When they finish with the materials at the station, instruct them to leave the materials in proper order for the next student.

1. Provide a bottle of club soda and a 25-cm^3 graduated cylinder.
   Set up a buret filled with 0.5 M NaOH (20 g/liter H_2O).
   Supply extra base in a labeled bottle and a funnel for pouring.
   Provide a dropper bottle of phenolphthalein.

   Place a sign to remind the student to *recap* the soda bottle as soon as the sample is removed.
   Be sure you titrate the sample yourself.

4. Provide a supply of litmus paper and 4 stirring rods (one per solution).

   Solution A is 6 M HCl (dilute concentrated HCl 1:1).
   Solution B is 1 M NaOH (10 g/250 cm^3 H_2O).
   Solution C is 0.5 M NaOH (5 g/250 cm^3 H_2O) or dilute B 1:1 with H_2O.
   Solution D is 3 M HCl (dilute concentrated HCl 1:4).

5. Set up a buret and fill to any level with water. A few drops of food coloring may be added for clarity.

6. Solutions A, B, C, and D can all be made by adding different amounts of food coloring to achieve different color intensities.

   Place 5 cm^3 of H_2O in each test tube lettered A, B, C, and D. Add 1 drop of color to A, two to B, three to C, and four to D.

   Make solution X resemble solution C. Place the solution (5 cm^3) in another test tube labeled X.

ANSWERS FOR SKILL-CENTERED MODULE TEST

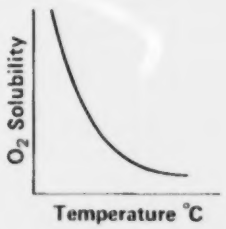
1. *; **2.** D; **3.** B; **4.** D; **5.** *;
6. C; **7.** A

*Evaluate according to teacher standards.

THE DELICATE BALANCE
Skill-Centered Module Test

1. Go to station #1 where you will find the necessary laboratory equipment to titrate a sample of soda for its CO_2 content. Take a 25-cm^3 sample of soda from the bottle using a graduated cylinder. *Recap the bottle immediately*. Place the sample in an Erlenmeyer flask and add 2 or 3 drops of phenolphthalein indicator. Titrate the sample using the base provided in the buret. Record the volume of base used next to #1 at the bottom of your answer sheet.

2. Examine the following graph.



You would conclude that the solubility of
A. gases decreases with decreasing temperature.
B. oxygen gas increases with decreasing temperature.
C. gases decreases with increasing temperature.
D. oxygen gas decreases with decreasing temperature.

3. While doing the experiment to determine the amount of PO_4^{3-} present in a water sample, a student does not add enough chemical to develop the blue color fully. The student's final value for the amount of PO_4^{3-} present will
A. be too high.
B. be too low.
C. be unaffected by the error.
D. make it impossible to finish the experiment.

4. Go to station #4 and determine which of the four solutions provided are acids. Use the litmus paper that is provided.

The acid solutions are:
A. A and B
B. A and C
C. B and D
D. A and D

5. Go to station #5 and determine the volume of liquid removed from the buret. The buret was originally filled to the 0.00-cm^3 level. Record the volume next to #5 at the bottom of your answer sheet.

6. Go to station #6 and examine the set of four test tubes (A, B, C, D) in the test-tube rack. Each test tube contains a different concentration of the solution in test tube A. You will also find another test tube labeled "X" at the station. Match the concentration of this solution to the tubes in the test-tube rack. The tube that contains a solution that most closely resembles the concentration of the solution in test tube X is:
A. test tube A
B. test tube B
C. test tube C
D. test tube D

7. A series of tests were conducted on samples containing known metal ions. The data from these tests are summarized below.

	Ion		
Test	**Ag^+**	**Hg^+**	**Pb^{2+}**
Cl^-	ppt* forms	ppt forms	ppt forms
H_2O (hot)	ppt insoluble	ppt insoluble	ppt soluble
NH_3	ppt soluble	ppt insoluble	ppt soluble

*ppt = precipitate

A water sample was then analyzed and the following results were obtained: A precipitate formed when a Cl^- ion was added. Part of the precipitate dissolved upon addition of hot water. The remaining precipitate was completely soluble in NH_3. From these tests you would conclude that the water sample contained the following ions:
A. Ag^+, Pb^{2+}
B. Hg^+, Pb^{2+}
C. Ag^+, Hg^+
D. Ag^+, Hg^+, Pb^{2+}

IAC TEST ANSWER SHEET

NAME		SCORE
DATE	CLASS PERIOD	
TEACHER		

Test Type (check)

☐ KNOWLEDGE-CENTERED
☐ SKILL-CENTERED

Module Test (check)

☐ INTRODUCTORY ☐ ORGANIC ☐ INORGANIC ☐ NUCLEAR
☐ PHYSICAL ☐ ENVIRONMENTAL ☐ BIOCHEMICAL ☐ COMPREHENSIVE

	A	B	C	D		A	B	C	D		A	B	C	D		A	B	C	D
1.	☐	☐	☐	☐	11.	☐	☐	☐	☐	21.	☐	☐	☐	☐	31.	☐	☐	☐	☐
2.	☐	☐	☐	☐	12.	☐	☐	☐	☐	22.	☐	☐	☐	☐	32.	☐	☐	☐	☐
3.	☐	☐	☐	☐	13.	☐	☐	☐	☐	23.	☐	☐	☐	☐	33.	☐	☐	☐	☐
4.	☐	☐	☐	☐	14.	☐	☐	☐	☐	24.	☐	☐	☐	☐	34.	☐	☐	☐	☐
5.	☐	☐	☐	☐	15.	☐	☐	☐	☐	25.	☐	☐	☐	☐	35.	☐	☐	☐	☐
6.	☐	☐	☐	☐	16.	☐	☐	☐	☐	26.	☐	☐	☐	☐	36.	☐	☐	☐	☐
7.	☐	☐	☐	☐	17.	☐	☐	☐	☐	27.	☐	☐	☐	☐	37.	☐	☐	☐	☐
8.	☐	☐	☐	☐	18.	☐	☐	☐	☐	28.	☐	☐	☐	☐	38.	☐	☐	☐	☐
9.	☐	☐	☐	☐	19.	☐	☐	☐	☐	29.	☐	☐	☐	☐	39.	☐	☐	☐	☐
10.	☐	☐	☐	☐	20.	☐	☐	☐	☐	30.	☐	☐	☐	☐	40.	☐	☐	☐	☐

For Skill-Centered Tests only, enter the numbers of all special questions and your answers in the spaces below.

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Materials List

Quantities are for a class of 30 students working in pairs.

*Optional items. These items depend on teacher choice. We have listed substitutions in the experiment discussion. Consult the specific experiment in the teacher's guide to determine use and quantities.

NONEXPENDABLE MATERIALS

Item	*Experiment*	*Amount*
Aquarium	34	1
Beakers, 50-cm^3	E-W1, 31	30
Beakers, 150-cm^3	38, 40, 41, 55	15
Beakers, 250-cm^3	38	1
Beakers, 600–1000-cm^3	13	15
Bicycle pumps	38	15
Bottles, collecting, 300-cm^3, with lids	16, 19, E-E	30
Bottle, droppers	E-E	15
Bunsen burners	13, 41, 55	15
Burets, 50-cm^3	13, 16, 40, 55, E-E	18
Buret clamps	16, 40	15
Buret stands	16, 55	15
Erlenmeyer flasks, 50-cm^3	38	1
Erlenmeyer flasks, 250-cm^3	13, 16, 40, E-E	30
Graduated cylinders, 10-cm^3	38	15
Graduated cylinders, 25-cm^3	38	15
Graduated cylinders, 50-cm^3	13, 38, 55	15
Graduated cylinders, 100-cm^3	16	15
Magnifying glasses	58	15
Medicine droppers	16, 29, 38	15
pH meter	E-W1*, 31*	1
Photovoltaic cell	59	1
Pipets, 10-cm^3 (calibrated)	7	8
Pipets, 1-cm^3 (with bulbs)	19, 38	5
Ring stands and rings	13, 41, 55	15
Rubber stoppers	19, 38	30
Screen, projection	34	1
Slide projector	34	1
Spectrophotometers	13*, 38*	2
Spectrophotometric tubes	13*, 38*	15
Stirring rods, glass	40	30
Test tubes, 18 × 150-mm	7, 13, 15, 19, 38, 41	60
Test-tube racks	7, 13, 15, 19, 38, 41	15
Thermometers, −10°C to 110°C	55	15
Voltmeter	59	1
Volumetric flasks, 250-cm^3	16, 38	4
Watch glasses or petri dishes	29	15
Wax pencil	7	1
Wire gauze	13, 41, 55	15

EXPENDABLE MATERIALS

Item	*Experiment*	*Amount*
Absorbing reagent	38	2 liters
Algae culture	7	15 cm^3
Ammonium chloride, NH_4Cl	16, 40	84 g
Ammonium hydroxide, NH_4OH, conc.	16, 40	695 cm^3
Ammonium molybdate, $(NH_4)_2MoO_4$	13	20 g
Ammonium, NH_3-NH_4Cl buffer	16	1000 cm^3
Ascorbic acid, $C_6H_8O_6$	13	5 g
Bags, plastic	E-E	15
Boric acid, H_3BO_3	7	6 g
Calcium carbonate, $CaCO_3$	16	2 g
Calcium chloride, $CaCl_2 \cdot 2H_2O$	7	40 g
Calcium nitrate, $Ca(NO_3)_2 \cdot 4H_2O$	7, 15	65 g
Citric acid	7	6 g
Cobalt chloride, $CoCl_2 \cdot 6H_2O$	7	0.1 g
Copper (II) sulfate, $CuSO_4 \cdot 5H_2O$	7	3 g
Cotton	7	30 wads
Detergent	15, E-W1	20 g
EDTA, ethylenediaminetetraacetic acid	16, 40	40 g
Eriochrome Black T solution	16, 40	0.7 g
Ethyl alcohol, C_2H_5OH	16	100 cm^3
Fertilizer, 5–10–10, ($N/P_2O_5/K_2O$)	7	2 g
Hydrochloric acid, HCL, conc.	16, 34	200 cm^3
Hydrogen peroxide, H_2O_2	38	50 cm^3
Hydroxylamine hydrochloride	16	5 g
Iron(III) citrate, $FeC_6H_{12}O_7 \cdot 3H_2O$	7	6 g
Litmus paper	16, E-W1, 31, 40	3 vials
Magnesium nitrate, $Mg(NO_3)_2 \cdot 6H_2O$	15	3 g
Magnesium sulfate, $MgSO_4 \cdot 7H_2O$	7, 16	6 g
Manganese chloride, $MnCl_2 \cdot 4H_2O$	7	4 g
Manganese sulfate, $MnSO_4$	55, E-E*	250 cm^3
Methylene blue	19	0.2 g
Methyl orange indicator	40	——
Milk, powdered	19	
Molybdenum oxide, MoO_3	7	0.1 g
N-NED reagent, N-(1-naphthyl)-ethylene diamine dihydrogen chloride	38	0.2 g
Nitric acid, HNO_3, conc.	40, 41	110 cm^3
Paper (5 cm × 5 cm)	58	15 pieces
Phenolphthalein indicator	55	1 small bottle
Phosphate detergent	13	30 g
Phosphoric acid, H_3PO_4, conc.	38	50 cm^3
Potassium chloride, KCl	7	1 g
Potassium dihydrogen phosphate, KH_2PO_4	7	0.5 g
Potassium iodine, KI	41	20 g
Potassium monohydrogen phosphate, K_2HPO_4	13	1 g
Potassium nitrate, KNO_3	7	2 g

EXPENDABLE MATERIALS (cont.)

Item	*Experiment*	*Amount*
Soap	15	1 g
Soda water	55	3 bottles
Sodium carbonate, Na_2CO_3	E-W1*, E-E*	5 g
Sodium hydroxide, NaOH	38, 40, 55, E-E*	12 g
Sodium iodide, NaI	E-E*	34 g
Sodium nitrate, $NaNO_2$	38	1 g
Sodium sulfate decahydrade	58	2 g
Sodium sulfite, Na_2SO_3	41	1 g
Sodium thiosulfate, $Na_2S_2O_3 \cdot 5H_2O$	34, E-E*	100 cm^3
Starch indicator	E-E1	150 cm^3
Starch, soluble	E-E1	1 g
Sulfanilamide	38	20 g
Sulfuric acid, H_2SO_4, conc.	13, 29, E-E	350 cm^3
Tartaric acid	40	2 g
Water, distilled	7, 13, 15, 16, 19, E-W1, 38, 55	
Yeast	19	
Zinc sulfate, $ZnSO_4 \cdot 7H_2O$	7	0.5 g

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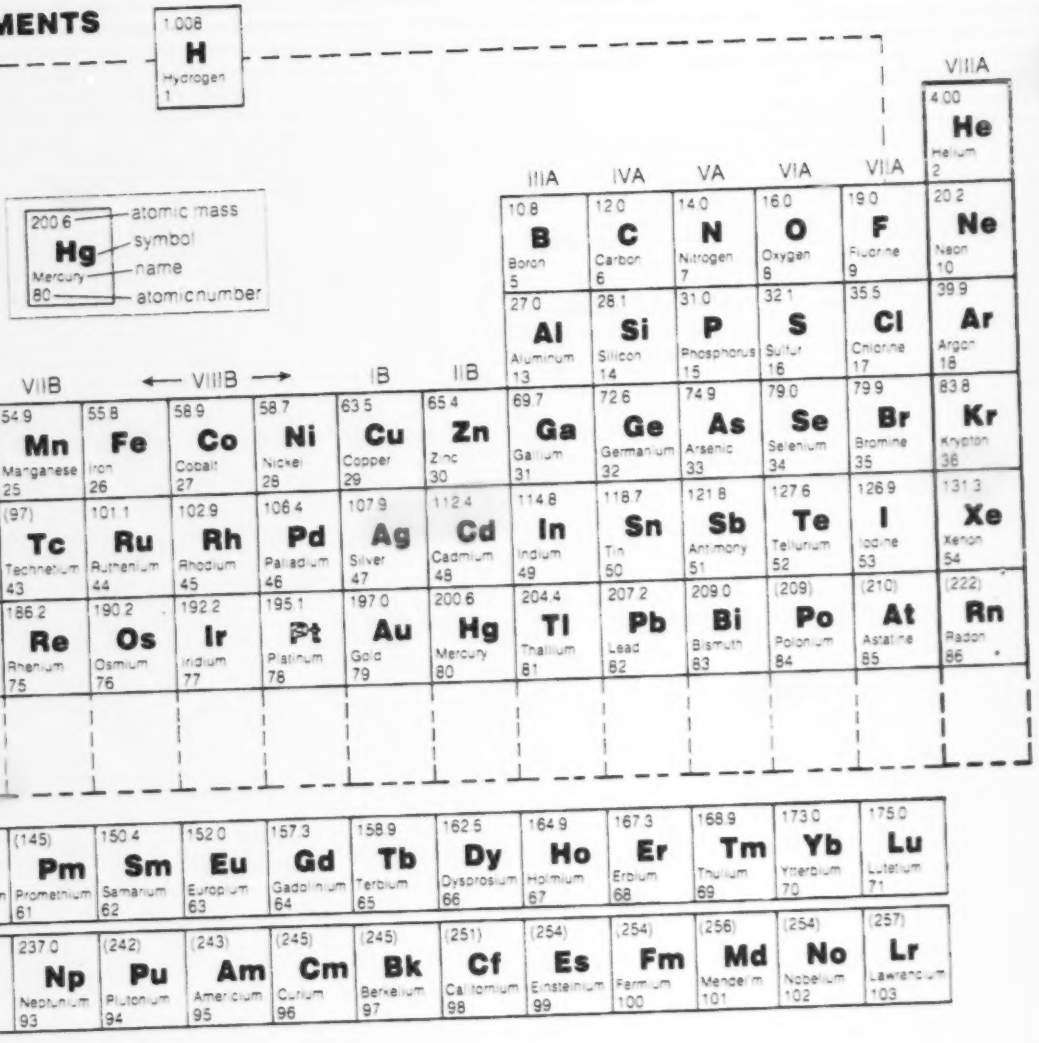
Table of International Relative Atomic Masses*

Element	Symbol	Atomic Number	Atomic Mass
Actinium	Ac	89	227.0
Aluminum	Al	13	27.0
Americium	Am	95	(243)**
Antimony	Sb	51	121.8
Argon	Ar	18	39.9
Arsenic	As	33	74.9
Astatine	At	85	(210)
Barium	Ba	56	137.3
Berkelium	Bk	97	(247)
Beryllium	Be	4	9.01
Bismuth	Bi	83	209.0
Boron	B	5	10.8
Bromine	Br	35	79.9
Cadmium	Cd	48	112.4
Calcium	Ca	20	40.1
Californium	Cf	98	(251)
Carbon	C	6	12.0
Cerium	Ce	58	140.1
Cesium	Cs	55	132.9
Chlorine	Cl	17	35.5
Chromium	Cr	24	52.0
Cobalt	Co	27	58.9
Copper	Cu	29	63.5
Curium	Cm	96	(247)
Dysprosium	Dy	66	162.5
Einsteinium	Es	99	(254)
Erbium	Er	68	167.3
Europium	Eu	63	152.0
Fermium	Fm	100	(257)
Fluorine	F	9	19.0
Francium	Fr	87	(223)
Gadolinium	Gd	64	157.3
Gallium	Ga	31	69.7
Germanium	Ge	32	72.6
Gold	Au	79	197.0
Hafnium	Hf	72	178.5
Helium	He	2	4.00
Holmium	Ho	67	164.9
Hydrogen	H	1	1.008
Indium	In	49	114.8
Iodine	I	53	126.9
Iridium	Ir	77	192.2
Iron	Fe	26	55.8
Krypton	Kr	36	83.8
Lanthanum	La	57	138.9
Lawrencium	Lr	103	(260)
Lead	Pb	82	207.2
Lithium	Li	3	6.94
Lutetium	Lu	71	175.0
Magnesium	Mg	12	24.3
Manganese	Mn	25	54.9
Mendelevium	Md	101	(258)
Mercury	Hg	80	200.6
Molybdenum	Mo	42	95.9
Neodymium	Nd	60	144.2
Neon	Ne	10	20.2
Neptunium	Np	93	237.0
Nickel	Ni	28	58.7
Niobium	Nb	41	92.9
Nitrogen	N	7	14.0
Nobelium	No	102	(259)
Osmium	Os	76	190.2
Oxygen	O	8	16.0
Palladium	Pd	46	106.4
Phosphorus	P	15	31.0
Platinum	Pt	78	195.1
Plutonium	Pu	94	(244)
Polonium	Po	84	(209)
Potassium	K	19	39.1
Praseodymium	Pr	59	140.9
Promethium	Pm	61	(145)
Protactinium	Pa	91	231.0
Radium	Ra	88	226.0
Radon	Rn	86	(222)
Rhenium	Re	75	186.2
Rhodium	Rh	45	102.9
Rubidium	Rb	37	85.5
Ruthenium	Ru	44	101.1
Samarium	Sm	62	150.4
Scandium	Sc	21	45.0
Selenium	Se	34	79.0
Silicon	Si	14	28.1
Silver	Ag	47	107.9
Sodium	Na	11	23.0
Strontium	Sr	38	87.6
Sulfur	S	16	32.1
Tantalum	Ta	73	180.9
Technetium	Tc	43	(97)
Tellurium	Te	52	127.6
Terbium	Tb	65	158.9
Thallium	Tl	81	204.4
Thorium	Th	90	232.0
Thulium	Tm	69	168.9
Tin	Sn	50	118.7
Titanium	Ti	22	47.9
Tungsten	W	74	183.8
Uranium	U	92	238.0
Vanadium	V	23	50.9
Xenon	Xe	54	131.3
Ytterbium	Yb	70	173.0
Yttrium	Y	39	88.9
Zinc	Zn	30	65.4
Zirconium	Zr	40	91.2

*Based on International Union of Pure and Applied Chemistry (IUPAC) values (1975).

**Numbers in parentheses give the mass numbers of the most stable isotopes.

PERIODIC TABLE OF THE ELEMENTS


1.008 H Hydrogen 1
200.6 Hg Mercury 80
atomic mass
symbol
name
atomic number
IA IIA IIIB IVB VB VIB VIIB ← VIIIB → IB IIB IIIA IVA VA VIA VIIA VIIIA
6.94 Li Lithium 3
9.01 Be Beryllium 4
23.0 Na Sodium 11
24.3 Mg Magnesium 12
39.1 K Potassium 19
40.1 Ca Calcium 20
45.0 Sc Scandium 21
47.9 Ti Titanium 22
50.9 V Vanadium 23
52.0 Cr Chromium 24
54.9 Mn Manganese 25
55.8 Fe Iron 26
58.9 Co Cobalt 27
58.7 Ni Nickel 28
63.5 Cu Copper 29
65.4 Zn Zinc 30
69.7 Ga Gallium 31
72.6 Ge Germanium 32
74.9 As Arsenic 33
79.0 Se Selenium 34
79.9 Br Bromine 35
83.8 Kr Krypton 36
85.5 Rb Rubidium 37
87.6 Sr Strontium 38
88.9 Y Yttrium 39
91.2 Zr Zirconium 40
92.9 Nb Niobium 41
95.9 Mo Molybdenum 42
(97) Tc Technetium 43
101.1 Ru Ruthenium 44
102.9 Rh Rhodium 45
106.4 Pd Palladium 46
107.9 Ag Silver 47
112.4 Cd Cadmium 48
114.8 In Indium 49
118.7 Sn Tin 50
121.8 Sb Antimony 51
127.6 Te Tellurium 52
126.9 I Iodine 53
131.3 Xe Xenon 54
132.9 Cs Cesium 55
137.3 Ba Barium 56
138.9 La* Lanthanum 57
178.5 Hf Hafnium 72
180.9 Ta Tantalum 73
183.8 W Tungsten 74
186.2 Re Rhenium 75
190.2 Os Osmium 76
192.2 Ir Iridium 77
195.1 Pt Platinum 78
197.0 Au Gold 79
200.6 Hg Mercury 80
204.4 Tl Thallium 81
207.2 Pb Lead 82
209.0 Bi Bismuth 83
(209) Po Polonium 84
(210) At Astatine 85
(222) Rn Radon 86
(223) Fr† Francium 87
226.0 Ra Radium 88
(227) Ac** Actinium 89
‡ 104
‡ 105
‡ 106
4.00 He Helium 2
10.8 B Boron 5
12.0 C Carbon 6
14.0 N Nitrogen 7
16.0 O Oxygen 8
19.0 F Fluorine 9
20.2 Ne Neon 10
27.0 Al Aluminum 13
28.1 Si Silicon 14
31.0 P Phosphorus 15
32.1 S Sulfur 16
35.5 Cl Chlorine 17
39.9 Ar Argon 18
* 140.1 Ce Cerium 58
140.9 Pr Praseodymium 59
144.2 Nd Neodymium 60
(145) Pm Promethium 61
150.4 Sm Samarium 62
152.0 Eu Europium 63
157.3 Gd Gadolinium 64
158.9 Tb Terbium 65
162.5 Dy Dysprosium 66
164.9 Ho Holmium 67
167.3 Er Erbium 68
168.9 Tm Thulium 69
173.0 Yb Ytterbium 70
175.0 Lu Lutetium 71
** 232.0 Th Thorium 90
231.0 Pa Protactinium 91
238.0 U Uranium 92
237.0 Np Neptunium 93
(242) Pu Plutonium 94
(243) Am Americium 95
(245) Cm Curium 96
(245) Bk Berkelium 97
(251) Cf Californium 98
(254) Es Einsteinium 99
(254) Fm Fermium 100
(256) Md Mendelevium 101
(254) No Nobelium 102
(257) Lr Lawrencium 103

†The most stable known isotopes are shown in parentheses.

‡The discovery of elements 104, 105, and 106 has been claimed by both American and Soviet scientists. The Americans have suggested the name *rutherfordium* and *hahnium* for 104 and 105; the Soviets have suggested the names *kurchatovium* and *nielsbohrium* for these same elements. No name has yet been proposed for element 106.

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